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INTERIM REPORT - UPPER OTTAWA STREET LANDFILL SITE STUDY, REFERENCE PAPER 9 : FEASIBILITY STUDY OF LANDFILL GAS CONTROL

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UPPER OTTAWA STREET
LANDFILL SITE STUDY

Reference 9

Feasibility Study
Landfill Gas Control
Upper Ottawa Street Landfill

UPPER OTTAWA STREET
LANDFILL SITE STUDY

Feasibility Study
Landfill Gas Control

Upper Ottawa Street Landfill

March, 1983
Ref. No. 0906

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March 4, 1983

Reference No. 906

Mrs. Ann Koven
Research Director
Upper Ottawa Street Landfill Study
42 James Street South
Suite 33
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Dear Ann:

Re: Final Report - Landfill Gas Control Feasibility Study

We are pleased to submit our final report on the landfill gas control feasibility study for the Upper Ottawa Street Landfill Site in Hamilton, Ontario. This report presents the study methodology, results from the various tests, conceptual design of a gas collection and flaring system, and conclusions, recommendations and implementation procedures.

Should you have any questions, please do not hesitate to contact us.

Yours very truly

CONESTOGA-ROVERS & ASSOCIATES LIMITED

Anthony J. Crutcher, P. Eng.

AJC/mm
Encl.

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1.0 INTRODUCTION

On August 25, 1982 Conestoga-Rovers & Associates Limited (CRA) received a request from the Upper Ottawa Street Landfill Gas Committee to prepare a proposal to determine the feasibility of recovery and flaring of landfill gas at the Upper Ottawa Street Landfill Site. This landfill site located in Hamilton, Ontario is a closed site previously operated by the Regional Municipality of Hamilton Wentworth. Figure 1.1 locates the site on a topographic map.

A proposal entitled "Feasibility Study, Landfill Gas Control, Upper Ottawa Street Landfill" was prepared by CRA and submitted to the Upper Ottawa Street Landfill Site Committee on September 1, 1982. This proposal outlined a program to determine the feasibility of recovering and flaring landfill gas at the site. On September 28, 1982, CRA was authorized to proceed with this project as outlined in the proposal.

Work on the project commenced shortly after receipt of authorization and this report represents the compilation of all the results. The report contains information pertaining to study methodology, landfill gas quality, quantity, production and recovery rates within the present site. Also included is information

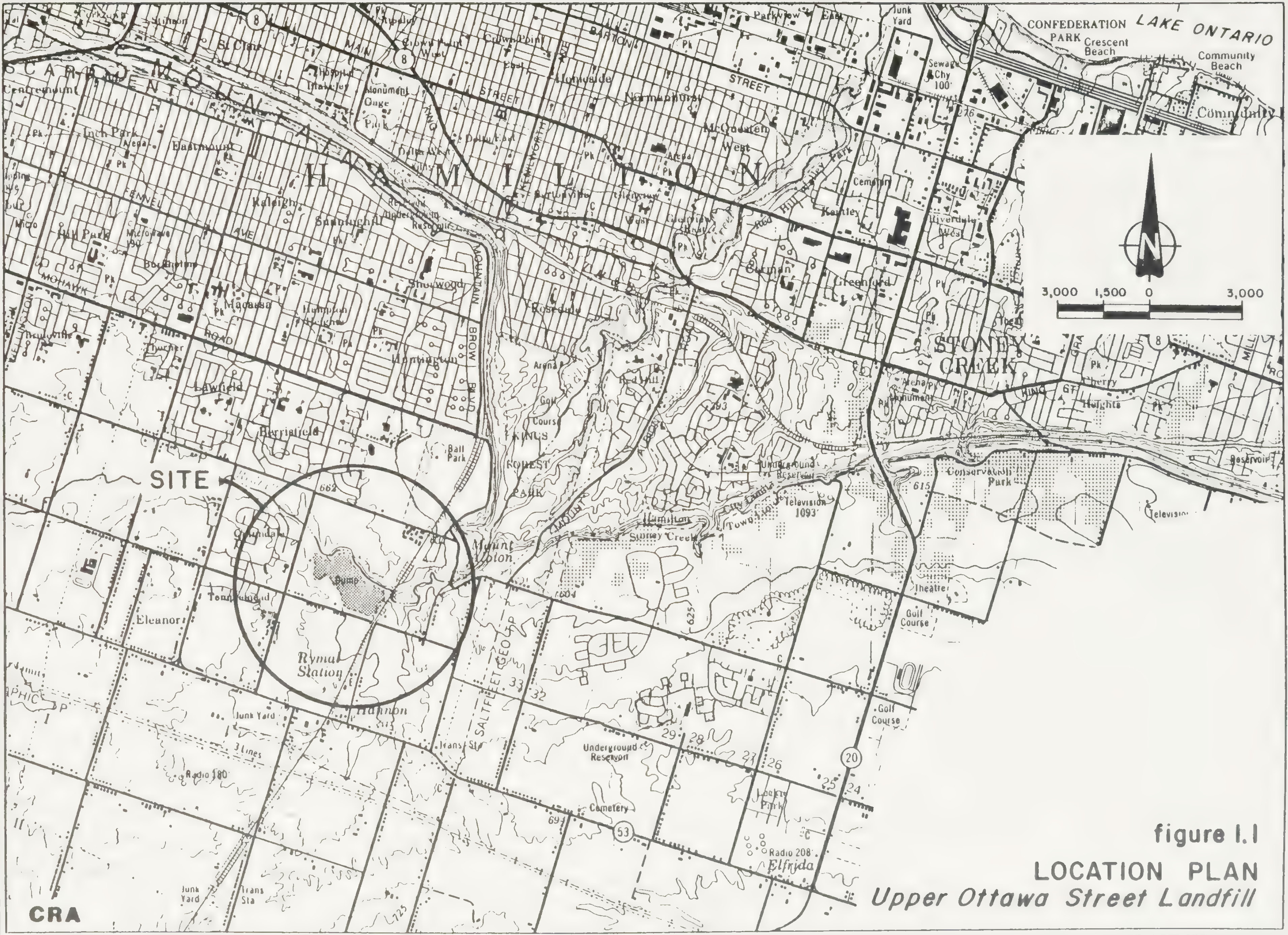

figure I.1

LOCATION PLAN

Upper Ottawa Street Landfill

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regarding landfill gas composition before and after landfill gas flaring and preliminary design concept and cost estimate for a gas recovery and flaring system.

2.0 STUDY METHODOLOGY

The study as proposed was divided into two phases.

PHASE I

The Phase I study evaluated the characteristics of the landfill gas from a field testing program. This work included installing a gas well and probes on the Stone Church Road side of the site and conducting two separate pumping tests on the site.

The first pumping test was used to ascertain the gas recovery rate and through the evaluation of gas pumping data, to determine design parameters for a gas control system. The second test was conducted to evaluate the landfill gas composition both prior to and after flaring of the landfill gas along with a comprehensive landfill gas analysis. This was done in order to ascertain whether the various components within the landfill gas are destroyed during burning, and to ensure that no harmful by-products of landfill gas combustion are emitted to the environment. All comprehensive analyses of the landfill gas samples were conducted by Mann Testing Laboratories (Mann).

The results of the Phase I work serve as an indicator of the desirability and technical feasibility of the collection and flaring of the landfill gas.

PHASE II

Phase II of the study entailed the preliminary conceptual design of the gas recovery and flaring system. A preliminary cost guide and estimates for the installation of the conceptual design are also given.

3.0 FIELD INSTALLATIONS

On October 6, 1982, CRA along with members of the Ottawa Street Landfill Site Committee and a representative from the Regional Municipality of Hamilton Wentworth toured the landfill site area. It was decided that the landfill gas well and monitoring system should be installed on the Stone Church Road side of the landfill site. This area was selected as being representative of average landfill conditions and was the area of the site having a noticeable odour.

The approximate location of the monitoring installations are shown on Map 1 and Figure 3.1.

3.1 LANDFILL GAS WELL

The landfill gas well was installed by Conestoga-Rovers & Associates Limited on October 13, 1982. This gas well was installed on the service road on the Stone Church Road side of the landfill site as located on Map 1 and Figure 3.1.

The landfill gas well consisted of a 36 inch diameter borehole augered to a depth of 32 feet, where water was encountered. A 4 inch diameter

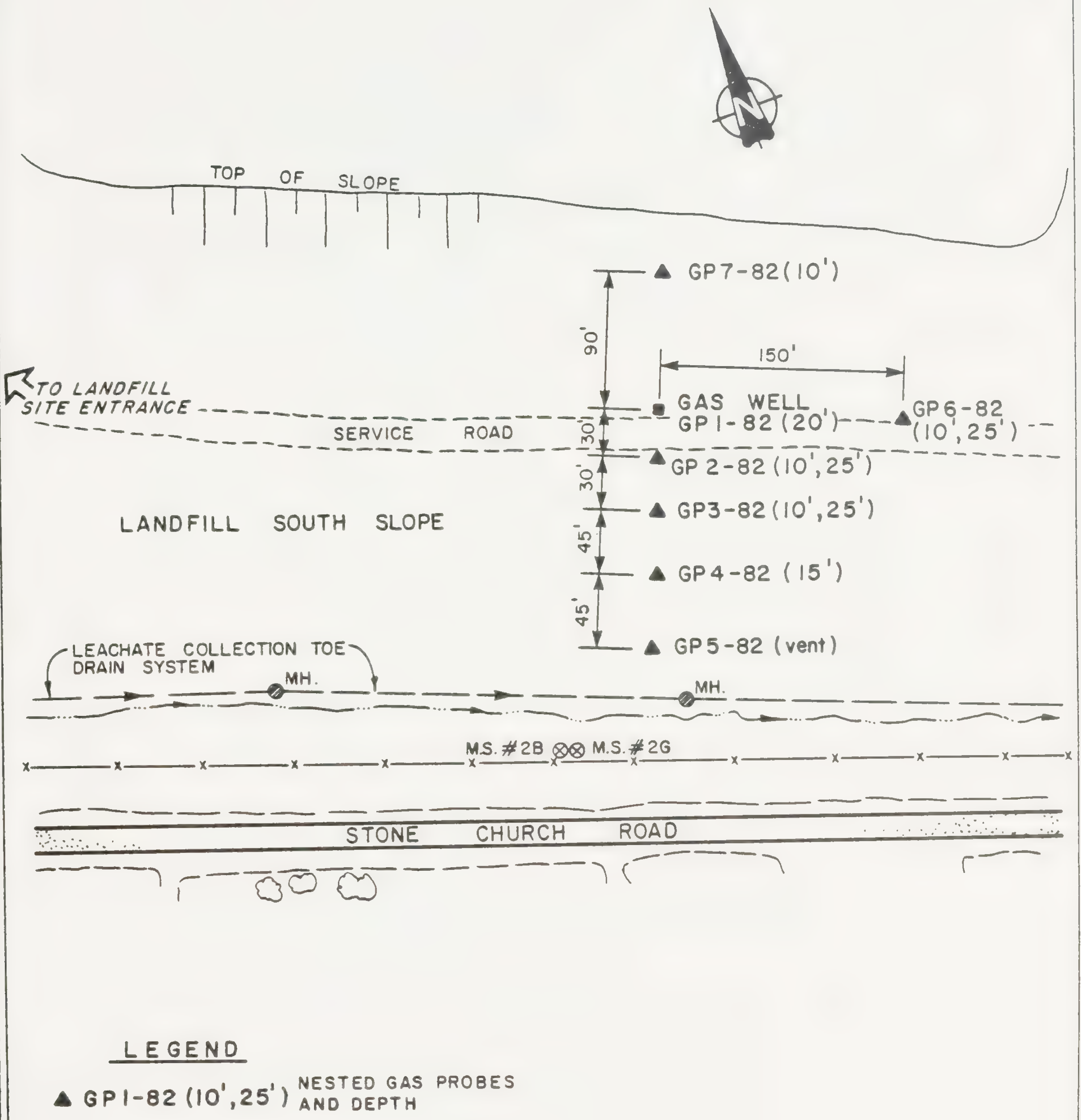

figure 3.1

GAS WELL & PROBE LOCATIONS
Upper Ottawa Street Landfill Site Study

CRA

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PVC well with an attached 20 foot section of perforated 4 inch PVC pipe wrapped with polypropylene filter cloth was then installed as shown on Figure 3.2. A gas monitoring probe was installed by the screened portion of the well for future monitoring. The borehole and well installation was then backfilled with 3/4 inch washed stone as shown on Figure 3.2.

The upper 6 feet of the landfill consisted of a clay silt till cover material mixed with what appeared to be furnace slag and some fly ash. From 6 feet to 35 feet refuse was encountered and was primarily of a domestic nature. This refuse had a high moisture content, was well decomposed and was ash like in appearance. High refuse temperatures were noted when drilling.

3.2 LANDFILL MONITORING PROBE NEST INSTALLATIONS

On October 14, 1982 five gas probe nests were installed radially from the well using an 8 inch hollow stem auger drilling rig. These gas probe nest locations ranged in distance from 30 feet to 150 feet from the well location. Figure 3.1 and Map 1 locate these probe nests in relation to the pumping well.

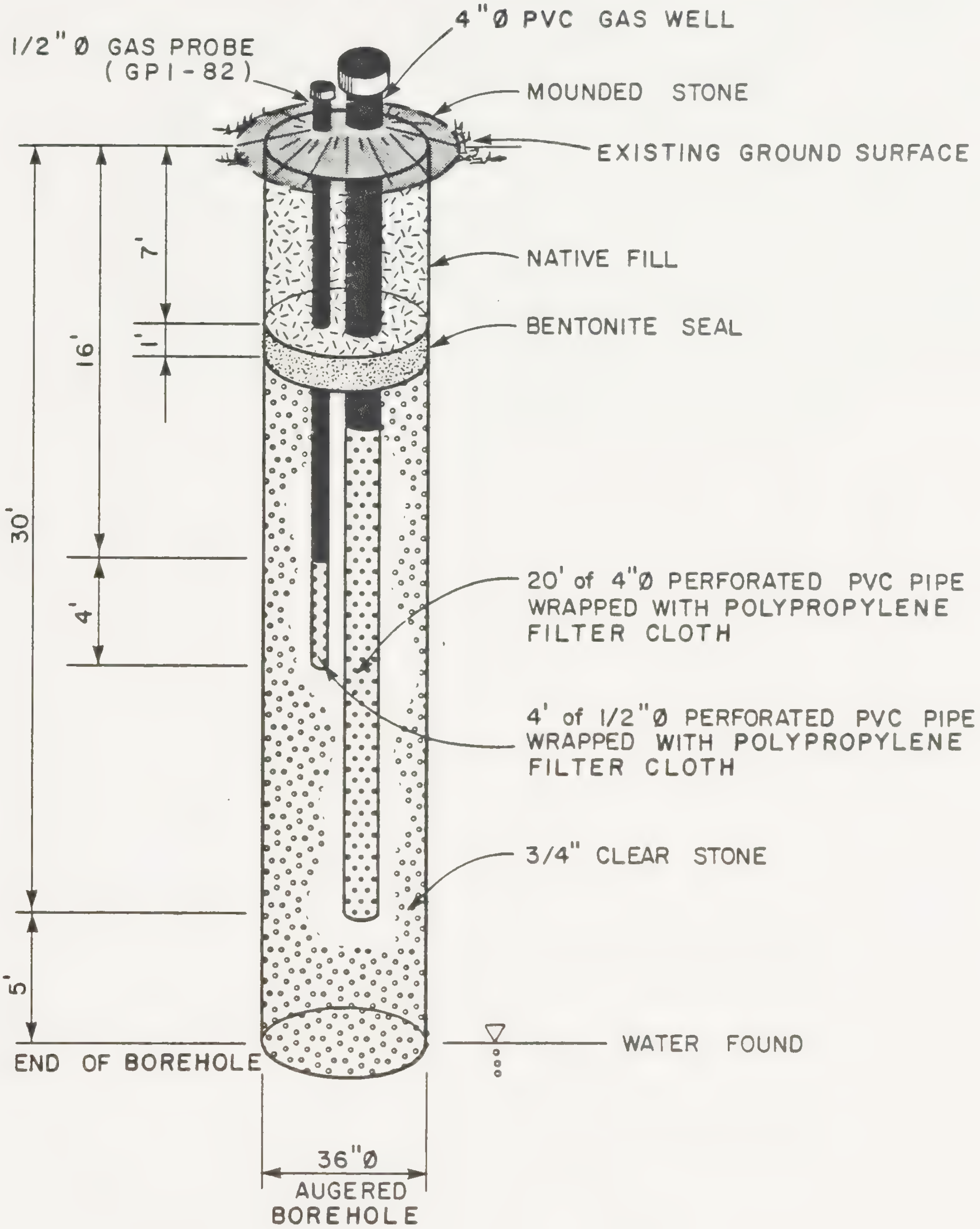

figure 3.2

GAS PUMPING WELL INSTALLATION

Upper Ottawa Street Landfill Site Study

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One or two probes were installed to different depths at each nest. Table 3.1 lists the number of probes and associated depth for each gas probe nest. Figure 3.3 illustrates a typical gas probe nest. As can be seen from Figure 3.3, a typical gas probe consists of half inch diameter PVC pipe with the bottom 4 foot section perforated. These perforations are covered with a polypropylene filter cloth.

TABLE 3.1

GAS PROBE NEST DESCRIPTION

PROBE NO.	DISTANCE FROM GAS WELL (feet)	NO. OF GAS PROBES	DEPTH OF PROBES (feet)
GP1-82	Gas Well	1	20
GP2-82	30 south	2	10 25
GP3-82	60 south	2	10 25
GP4-82	105 south	1	15
GP5-82	150 south	1 (existing vent)	near surface
GP6-82	150 east	2	10 25
GP7-82	90 north	1	10

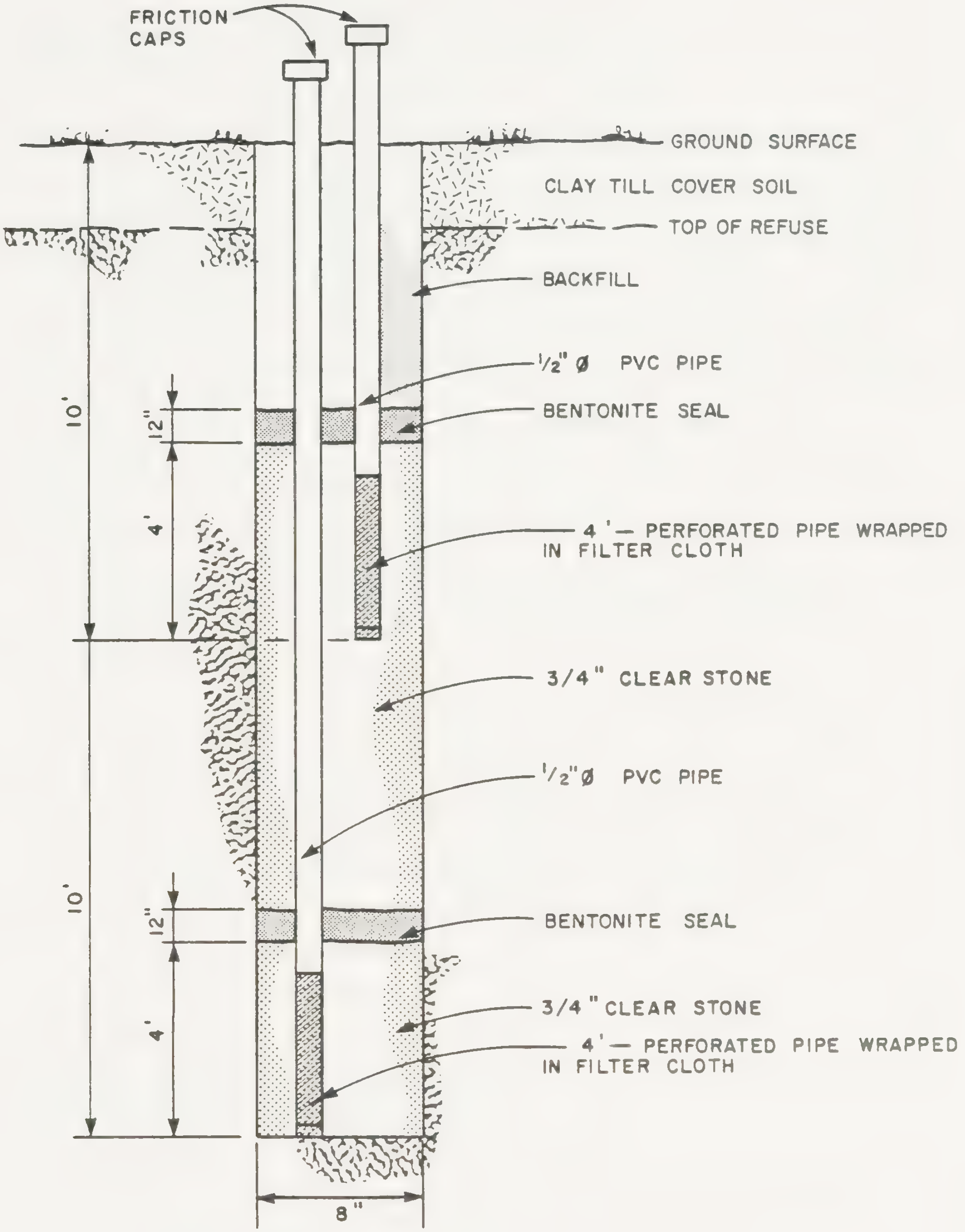

figure 3.3

TYPICAL NESTED GAS PROBES

Upper Ottawa Street Landfill Site Study

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4.0 LANDFILL GAS PUMPING AND FLARING TEST NO. 1

4.1 GENERAL

On October 20 and October 21, 1982 a 32 hour pumping test was conducted by CRA. Landfill gas was pumped from the gas well at a constant rate of 40 cfm using a "Roots" rotary lobe gas pump powered with a one horse power electric motor. Electric power was supplied using a portable gasoline powered generator. The landfill gas extracted was continously flared in a flare manufactured by CRA. Figure 4.1 illustrates the landfill gas pumping and flaring system.

At selected time intervals the landfill gas concentration, pressure and temperature were measured at the gas well and gas monitoring probes.

4.2 PUMPING TEST DATA COLLECTION

Pumping test data was collected at all gas probes and at the well head at 2 to 3 hour intervals throughout the entire 32 hour test. The data collected included pressures, combustible gas readings, and gas probe temperatures.

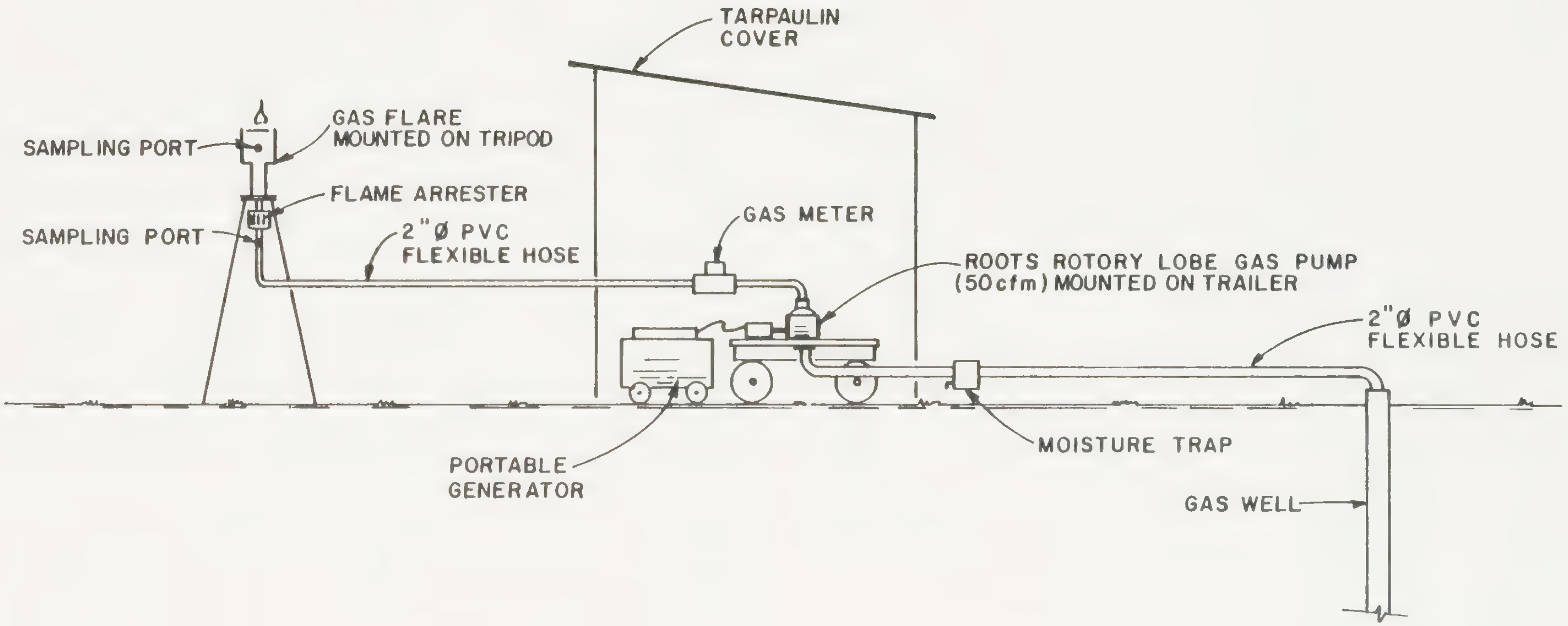

figure 4.1

GAS PUMPING AND FLARE DETAIL

Upper Ottawa Street Landfill Site Study

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Pressures at all probes were taken using an inclined manometer. Combustible gas (methane) readings were taken using a portable gas explosion meter. Gas probe temperatures were taken with a "YSI" telethermometer.

Appendix A contains all the data as measured during the 32 hour test at all probe nests and at the well head.

4.3 GAS FLARE TEMPERATURE AND SAMPLING

Flare flame temperatures were periodically measured using an "IRCON" optical pyrometer.

Landfill gas samples were taken at the well head using gas sampling bags by both CRA and Mann. Mann also obtained pre and post-combustion gas samples at the flare periodically throughout the test. The report containing the complete Mann testing procedure for pumping test No. 1 is contained in Appendix B of this report.

4.4 PUMPING TEST DATA RESULTS AND ANALYSIS

A) COMBUSTIBLE GAS ANALYSIS

Combustible gas (methane) concentrations at the well head were relatively high and ranged from 55% to 65% as measured by the field explosion meter. Table 4.1 presents the well head methane concentrations.

As mentioned previously, landfill gas samples were taken in field gas sampling bags at the well head periodically during the test. These samples were then analyzed by CRA using a Fisher Model 1200 Gas Partitioner. The samples were analyzed for CO_2, O_2, N_2, CH_4 and CO. The results of this analysis are presented in Table 4.2. The methane concentrations analyzed in the laboratory ranged between 56% to 59% by volume which correspond closely to field readings using the explosion meter.

Mann also analyzed a duplicate set of these gas samples. Mann methane gas concentrations varied from 34.6% to 44.8% methane. This range is somewhat lower than the range as analyzed by CRA.

TABLE 4.2

LABORATORY GAS ANALYSIS OF UNFLARED LANDFILL GAS

		Concentration (% by Volume)							
Date	Time	CO_2	H_2	O_2	N_2	CH_4	CO	Other	CH Field Measurement
October 20, 1982	10:00	29	ND	ND	1.7	59	ND	10	60
	13:00	29	ND	ND	1.7	56	ND	13	--
	19:00	29	ND	ND	4.1	58	ND	9	53
	23:30	29	ND	ND	4.6	58	ND	8	63
October 21, 1982	3:30	29	ND	ND	8	56	ND	7	64
	5:00	29	ND	ND	6	55	ND	9	61
	11:20	29	ND	ND	4.6	55	ND	11	57

NOTE:

1) Analysis conducted by Conestoga-Rovers & Associates Limited using a Fisher Model 1200 Gas Partitioner

2) ND - Not Detected

As discussed in the Mann report found in Appendix B, the pump used for sampling was not completely sealed and, therefore, probably diluted the Mann landfill gas samples with air.

B) PRESSURE ANALYSIS

Pressures were recorded at regular intervals during the pumping test through use of an inclined manometer. The monitoring data is compiled in Appendix A.

Initially, all pressures monitored before the start of the pumping test were positive. The pressures ranged from 0.14 inches of water to 0.62 inches of water. The pressure at the goose neck vents, shown on Map 1 near the leachate collection system at the toe of the site, had initial pressure readings of 0.08 inches of water.

These pressures are relatively high for a landfill site. This would either indicate that there is a relatively high rate of landfill gas production at this site or a fairly gas impermeable cover, which has allowed gas to buildup beneath the surface of the landfill.

However, the noticeable odour and the existing erosion of the landfill would suggest that the cover is not acting as a barrier limiting gas venting.

Given the above, it is postulated that production rate in conjunction with some limited amount of buildup beneath the cover is responsible for the initial high pressure readings recorded at the site. Table 4.3 shows the initial pressure readings on all the installed probes and the goose neck vents.

Table 4.3 also presents the pressures in all the probes and the goose neck vents at 31 hours into the pumping test. As can be seen from this table, all probes were influenced to some degree by the pumping at the well.

Only at the well itself, and at GP2-82 (10') was the pressure reversed from positive to negative. Pressures in GP2-82 (10') changed from an initial reading of +0.54 to a reading of -0.32 inches of water during pumping. This negative pressure at GP2-82 (10') would indicate that all gas being produced in the immediate vicinity of GP2-10 is being drawn towards the well and no gas is building

TABLE 4.3.

PRESSURE COMPARISON

PROBE	INITIAL PRESSURE BEFORE PUMPING (Inches of H_20)	PRESSURE AT 31 HOURS (Inches of H_20)
GP1-82 (Well)	0.56	-0.70
GP2-82 (10')	0.54	-0.32
GP2-82 (25')	0.36	0.34
GP3-82 (10')	0.60	0.12
GP3-82 (25')	0.62	0.18
GP4-82 (15')	0.56	0.16
GP5-82 (Goose Neck Vents)	0.08	0.06
GP6-82 (10')	0.44	0.02
GP6-82 (25')	0.54	0.16
GP7-82 (10')	0.14	0.04

up below the cover soils. This is an important point to consider in the design of a landfill gas control system.

The pressure at any location in the site should be negative (or very low positive pressure) to ensure that little gas is venting through the cover. For example, a GP4-82 (10') showed a pressure decrease from +0.56 to +0.16 inches of water during pumping. This would indicate that the probe was being influenced by the pumping, but since the pressure is still highly positive at the probe, landfill gas is still building up under the cover.

The zone of negative pressure or complete gas control at a 40 cfm pumping rate has been estimated from pressure data to be approximately 50 feet from the pumping well.

Due to the short term nature of the pumping test, it is difficult to predict or estimate a long term gas recovery rate for the site. It is possible that gas being drawn from beyond this 50 foot radius is still being drawn from storage and an equilibrium between pumping rate and gas production rate has not been achieved.

For the purposes of calculating the gas recovery rate from this test, it has been assumed that the majority of gas collected by the well is recovered within this 50 foot radius, or zone of negative influence as described.

In order to calculate, the maximum recovery rate it is assumed that the majority of the gas recovered from the 50 foot radius area was collected from storage and gas production above the water table. The volume of refuse above the water in a 50 foot radius from the well is estimated to be 9,300 yd^3. At an assumed density of 1,000 pounds of refuse per cubic yard of volume and a pumping rate of 40 cfm yields a landfill gas recovery rate from pumping of 2.3 cubic feet per pound of refuse per year (at approximately 50% methane). This recovery rate is unrealistic and it is suspected that long term pumping would indicate a lesser value.

Assuming on the longer term that gas has been removed from storage above the water table and equilibrium has been achieved between the gas pumping and gas production rate above and below the water table within the 50 foot radius a landfill gas recovery rate of 0.9 cubic feet per pound of refuse per year has been calculated. For this

calculation a total refuse volume of 20,400 yd^3 above and below the water table was used and assumes a refuse density of 1,200 lbs/yd^3. The refuse density of 1,200 lbs/yd^3 was used as the refuse is burried up to at least 70 feet and would undergo more compaction than refuse above the water table.

Calculating the gas recovery rate using the total measured zone of influence by the definition of percentage change in pressure (5% change defines boundary) and factoring for this percentage yields a recovery rate of on the order of 0.3 $ft^3/lb/yr$.

The gas recovery rate range of 0.3 to 0.9 ft^3 of landfill gas per pound of refuse per year is high as compared to typical ranges in gas recovery rates from operating gas recovery facilities of 0.05 to 0.15 cf/lb/yr. Similar short term pumping tests conducted by CRA at other landfill sites in Southern Ontario, indicated a range of 0.17 to 0.40 $ft^3/lb/yr$. Given the above, the gas recovery rate although difficult to quantify, can be definitively stated to be very high. This gas recovery/production rate would be indicative of having optimal conditions at the site for gas

production as was found, that being, the high moisture content within the refuse (as reflected by the high water table) and the elevated temperatures (in the order of 30°C to 50°C).

The Regional Municipality of Hamilton-Wentworth indicated that the landfill site has approximately 3 million cubic yards of refuse in place. Assuming an average density of 1,000 lbs/cubic yard, the total amount of refuse in the site is approximately 1.5 million tons.

Gas production rates from actual sites and studies as taken from the literature are in the range of 0.1 to 0.6 scf/lb/year. Considering that the measured gas recovery rate of the site is high, the gas production rate of 0.6 scf/lb/year is used to calculate the total gas production rate. Based on the above, it is calculated that the gas production rate is estimated to be 1.8×10^9 ft^3/yr.

The gas recovery rate would be less than the gas production rate and would depend on system design and effectiveness. Detailed testing of the actual gas recovery facility would indicate the level of recovery.

C) TEMPERATURE ANALYSIS

Temperatures as recorded during the pumping test can be found in Appendix B. Table 4.4 lists initial temperatures before pumping and temperatures at the 27th hour during the pumping test. As can be seen, the temperatures in the landfill site stayed relatively constant and ranged between 35°C to 55°C during the complete pumping test. These temperatures are very near to optimal temperatures for methane production as both mesophillic and thermophillic methanogenic bacteria can exist in this temperature range. This would make for high methane production as indicated by the high test methane concentrations and the high positive initial pressures at the landfill site. The high moisture content of the refuse that was found during well and probe installation, also has a positive effect on the methane production.

4.5 FLARE TEMPERATURES AND SAMPLES ANALYSIS

A) FLARE TEMPERATURES

Flare temperatures were measured during the test at the top of the flare through the use of an optical

TABLE 4.4.

TEMPERATURE COMPARISONS

PROBE	INITIAL TEMPERATURE (°C) BEFORE PUMPING	TEMPERATURE (°C) AFTER 27 HOURS
GP1-82 (Well)	54	53
GP2-82 (10')	35	36
GP2-82 (25')	53	54
GP3-82 (10')	31	31
GP3-82 (25')	42	42
GP4-82 (15')	32	32
GP5-82 (Goose Neck Vents)	18 (ambient)	11 (ambient)
GP6-82 (10')	50	49
GP6-82 (25')	43	43
GP7-82 (10')	35	36.5

pyrometer by CRA. These temperatures varied greatly during the test period. This can be partially accounted for by the winds during the test period on the site. These winds consistently changed the fuel to air mixture ratio for combustion and hence changed the combustion temperatures. Temperatures were measured in a range of 400°C to 800°C. During periods of relative calm winds the temperature was measured at approximately 600°C.

During the pumping and flaring test, the weather report estimated wind gust in the area between 40 to 50 miles per hour. Even with these high gusts, the flare continually burned throughout the test.

B) FLARE GAS SAMPLE ANALYSIS

The landfill gas was sampled before and after the flaring using air bags and tenax tubes by Mann. The analysis of the gas samples indicated the presence of several volatile organic compounds in relatively high concentrations. Table 4.5 shows the listing of the different components analyzed in the landfill gas by Mann at different periods during the test. This table shows both pre and post-flaring concentrations. It should be noted

TABLE 4.5

AIR BAGS ANALYSIS**

CONCENTRATIONS OF COMPONENTS IN FLARE GASES IN PPM (v/v)

	Oct. 20/82 1:30 p.m.		Oct. 21/82 1:00 p.m.		Oct. 21/82 2:00 p.m.		Oct. 21/82 3:00 p.m.	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
n-hexane	29	18	23	17	22	17	25	11
dichloroethylene	20	10	16	9	13	12	32	5
acetone	608	533	486	364	453	408	547	261
tetrahydrofuran	17	11	16	11	16	12	16	4
methyl ethyl ketone	154	88	99	61	90	81	92	44
benzene	7	6	8	5	7	7	6	2
toluene	256	133	242	157	244	221	245	64
ethyl benzene	81	40	71	46	79	65	71	28
trichloroethylene	1.4	0.8	1.4	0.5	1.1	0.8	1.2	0.2
1,4 dioxane	10	4	9	4	10	7	5	1
*butene (H/C)	10	5	8	5	6	6	8	5
*butanol	13	6	11	6	9	8	9	3
*hexane (H/C)	9	5	8	5	6	5	8	2
*hexanone (H/C)	90	39	86	41	84	81	58	7
*p-xylene	34	20	51	25	41	37	23	6
*o-xylene	192	105	220	125	205	170	184	61
*m-xylene	84	42	85	58	86	80	86	28
*C_3-benzene	10	2	15	7	19	9	11	2

* Approximate Concentrations

** Analyzed by Mann Testing Laboratories Ltd.

that it is suspected that these gas samples were diluted with air as described previously.

As illustrated by Table 4.5 there is not a high degree of destruction of many of the components after landfill gas flaring. This is due mostly to the inefficient burning of the flare. Combustion chemistry indicates that there must be at least twice as much oxygen as methane by volume for efficient burning.

This degree of oxygen enrichment in the fuel was not obtained in the first flaring during pumping test No. 1. This was evidenced by the burning characteristic of the flame during the test. The flame burned at the top of the flare enclosure and not inside the enclosure. This indicates that there was not enough oxygen for efficient burning within the flare enclosure and the flare did not burn efficiently until it was mixed completely with outside air at the top of the flare.

Due to this flare equipment problem, the degree of destruction of volatile organics in the landfill gas after flaring was not possible to measure.

Further information on the landfill gas sampling and analysis can be found in the Mann report presented in Appendix B.

5.0 LANDFILL GAS PUMPING AND FLARING TEST NO. 2

5.1 GENERAL

The first pumping and flaring test provided good information with respect to gas composition, production rates and zone of influence from pumping. However, the gas flare did not contain the flame due to lack of oxygen and proper sampling was not possible. It was therefore decided by the Upper Ottawa Street Landfill Committee to repeat the test with specific emphasis on obtaining information on the efficiency of destruction for compounds, particularly chlorinated organics during flaring.

Prior to conducting the second flaring test, a literature search was conducted and modifications to the original pumping and flaring equipment to create efficient burning were implemented in order to assure successful completion of the flaring test. The literature review indicated that a very limited amount of published information is available with respect to landfill gas flaring and effects, is found in Appendix C.

A combustion engineer from the University of Waterloo was contacted to discuss flare

design and methods to improve combustion and to obtain maximum flare temperatures. The combustion engineer noted that the first flaring test fuel mixture was methane rich and that air had to be introduced into the system at a ratio of at least 5:1 to create efficient burning.

Through these discussions, the flare system and pumping mechanism were redesigned as shown on Figure 5.1. As is shown in Figure 5.1, atmospheric air was injected into the flare using a blower. This air was directed in an opposite flow direction to the landfill gas in order to maximize the amount of mixing. The quantity of gas and air was controlled by valves and was metered for measuring flow rates and the quantity of landfill gas used. From these measurements it was possible to calculate the ratios of landfill gas to outside air mixture and to determine the optimum/practical ratio for efficient combustion.

On December 21 and December 22, 1982, the second landfill gas pumping and flaring tests were conducted on the Upper Ottawa Street Landfill Site by CRA and Mann. These tests were conducted to ascertain whether the flaring of landfill gas destroyed most contaminants and odorous components in the

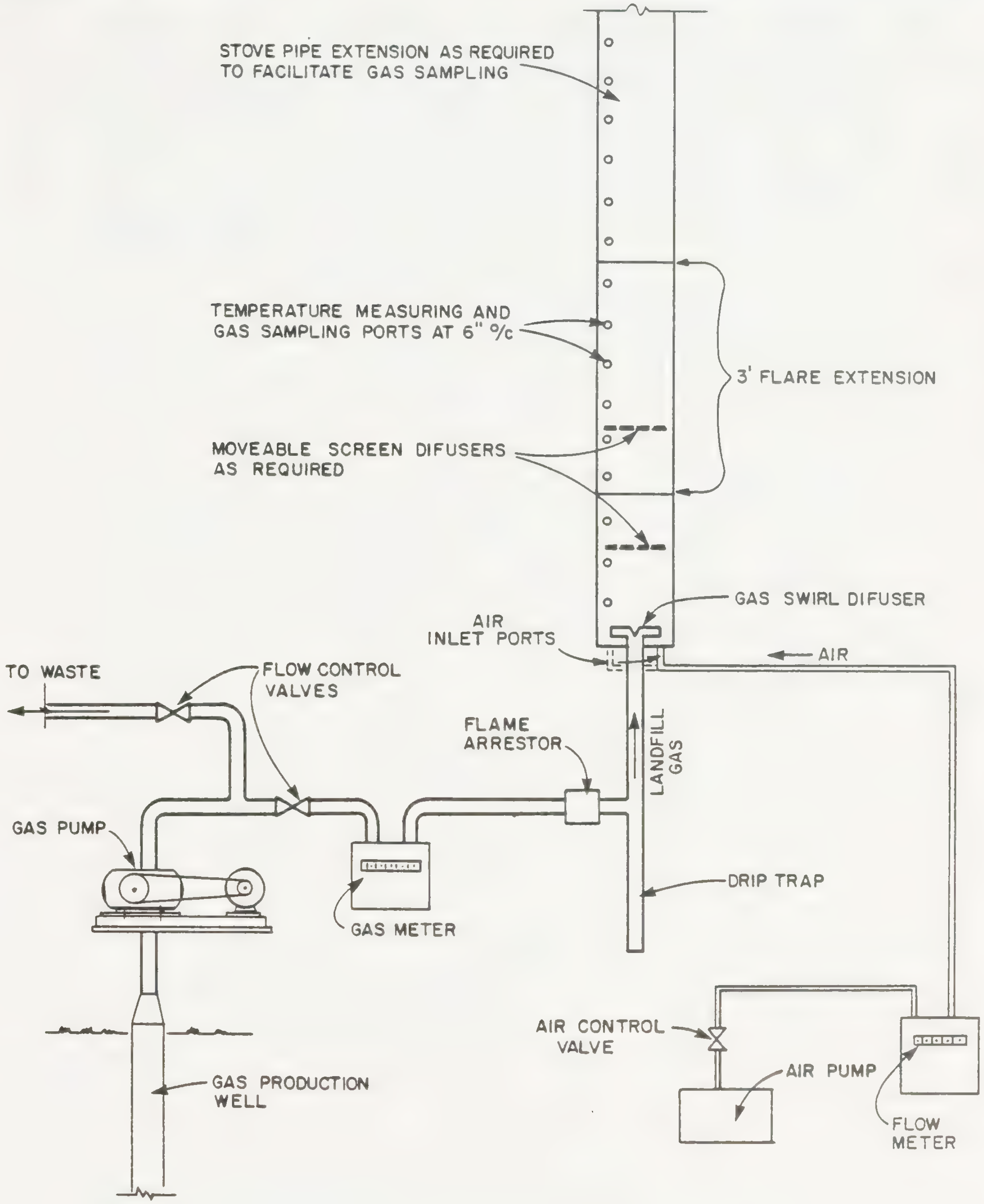

figure 5.1

SCHEMATIC OF
RE-DESIGNED LANDFILL GAS FLARING
Upper Ottawa Street Landfill Site Study

CRA

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landfill gas and whether the combustion of landfill gas created any toxic components that would be released to the environment. The tests were conducted using the landfill gas well previously installed and used for pumping Test No. 1.

The test methodology for the combustion test is outlined below:

1. Vary the landfill gas to air mixture ratio and determine the flare flame temperature throughout the flaring enclosure with a pyrometer. These measurements were taken through the ports as shown in Figure 5.1.

2. Determine the most efficient/practical landfill gas to air ratio from the above data.

3. Maintain the selected landfill gas to air ratio and collect samples of flare combustion products for analysis by Mann at this ratio.

5.2 OPTIMUM LANDFILL GAS TO AIR RATIO SELECTION AND TEMPERATURE ANALYSIS

The landfill gas to air ratio was varied by means of valve adjustment as shown on

Figure 5.1 from a ratio of 1:4.7 to 1:20. Temperatures were recorded for the flare gas at the different testing ratios. These temperatures were taken by means of a Hoskins type AH pyrometer. Table 5.1 presents the results of the testing at the various ratios selected. The 1:20 ratio was the maximum ratio obtainable during the test, due to equipment limitations.

Figure 5.2 presents a graph of maximum flame temperature versus landfill gas to air ratio from data taken from Table 5.1. This figure shows that above the 1:10 ratio very little benefit is derived in temperature. For example, the difference in maximum temperature between a 1:10 ratio and a 1:20 ratio is only 20°C.

Therefore, the 1:10 ratio was chosen as the most practically efficient ratio for efficient combustion of landfill gas. All sampling was the conducted at this setting. The maximum measured temperature for the 1:10 ratio as shown in Table 5.1 was 950°C.

TABLE 5.1

LANDFILL GAS TO AIR RATIO

PORT	1:4.7	1:7	1:9	1:10	1:20
			Temperature °C		
1	720	875	910	950	970
2	810	810	690	710	640
3	650	820	530	670	550
4	650	730	490	560	470
5	600	590	390	500	540
6	590	540	-	470	440
7	520	510	-	-	-
8	580	-	-	-	-
9	-	-	-	-	-
TOP	300	-	-	430	380
Flame Height	Flame Throughout Enclosure	Flame Maintained in Bottom 3'	Flame Maintained in Bottom 1'	Flame Maintained in Bottom 1'	Flame Maintained in Bottom 1'
Flame Colour	Blue/White	Blue/White	Blue	Blue	Blue

- = Not recorded

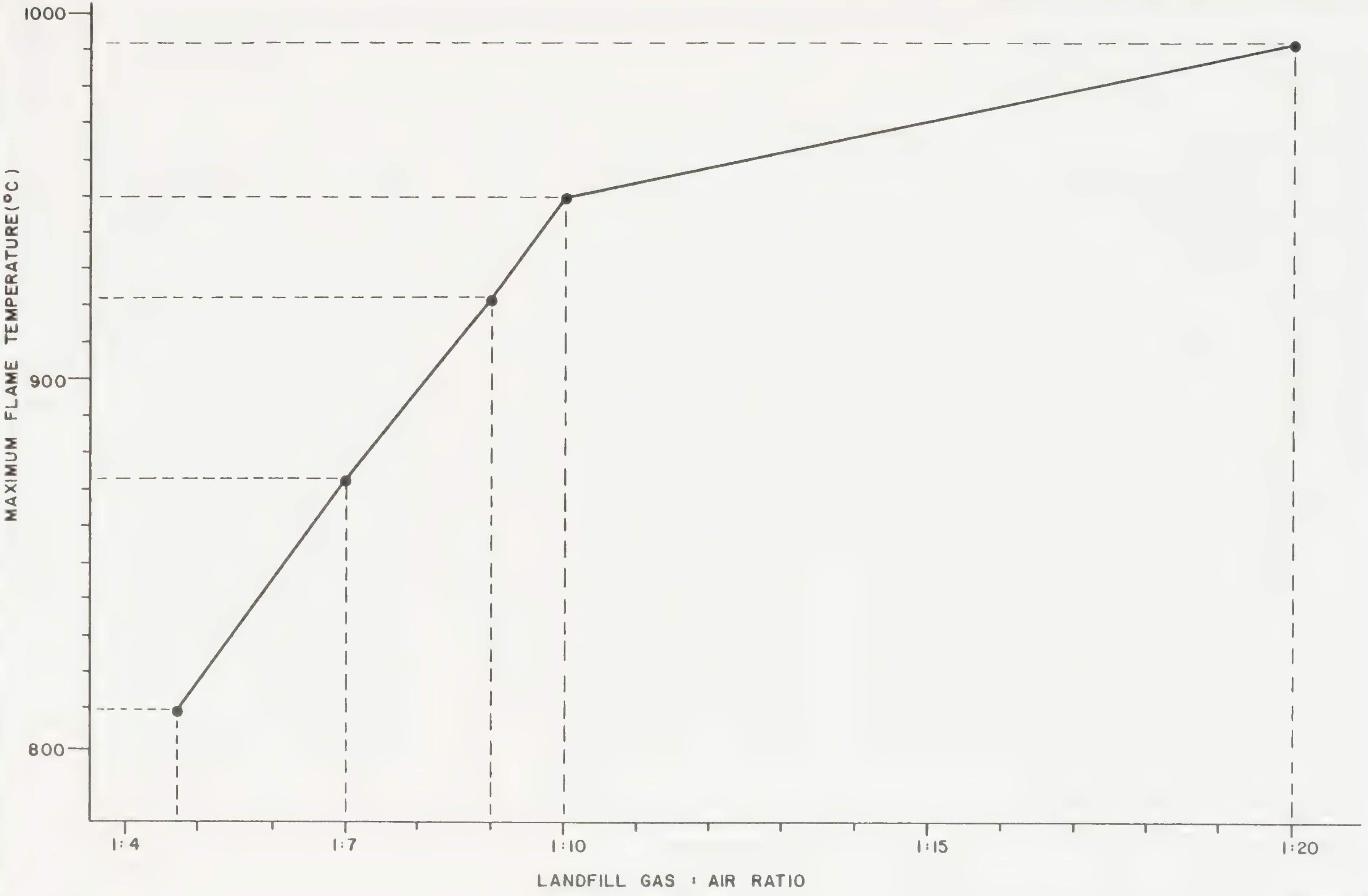

figure 5.2

GRAPH OF
LANDFILL GAS TO AIR RATIO Vs. MAXIMUM FLAME TEMPERATURE
Upper Ottawa Street Landfill Site Study

CRA

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5.3 LANDFILL GAS SAMPLING

Gas sampling was conducted using an oilless vacuum pump supplied by Mann. Samples of both pre and post-combustion gas at a 1:10 ratio were taken through copper tubing connected to the vacuum pump. All samples were taken at Port No. 5 which was located approximately 3 feet from the landfill gas air mixture point and approximately half way up the flare enclosure. The landfill gas concentration remained at a constant 58% throughtout the sampling period.

Samples were taken by both tenax tubes sample and gas bags. For further information with respect to the gas sampling techniques, refer to the Mann report entitled "Chemical Analysis of Pre and Post-Flare Gases" reproduced in Appendix D of this report.

5.4 LANDFILL GAS SAMPLING ANALYSIS AND RESULTS

All sampling analysis was conducted by Mann using a combination of GC/MS equipment. Further explanation of the analytic techniques that were used can be found in the Mann report contained in Appendix D of this report.

The pre and post-landfill gas flare samples analysis indicated that the combustion efficiency for most of the organics quantified greater than 90%. Benzene, napthalene and benzofuran were destroyed to a lesser degree with combustion efficiencies, ranging from 50% to 80%. Styrene, benzaldehyde, and methyl benzaldehyde concentrations very low to begin with, changed very little and may have actually increased. The burning of the landfill gas eliminated the odour, and odour producing components within the landfill gas.

6.0 LANDFILL GAS PUMPING TEST #3

6.1 GENERAL

On February 21, and February 22, 1983 a third landfill gas pumping test was conducted on the Upper Ottawa Street Landfill Site by CRA and Mann. These tests were conducted to compare concentrations of selected compounds present in the pumped landfill gas with concentrations of the same compounds present in samples of landfill gas passively venting from two gooseneck vents and a gas nest probe.

6.2 LANDFILL GAS SAMPLING ANALYSIS AND RESULTS

Landfill gas was collected in air sampling bags for all samples analysed.

Six key compounds were to be analysed for in this test. These were benzene, toluene, total xylenes, naphthalene, dichlorobenzene, 1,1,1 trichloroethane, and tetrachloroethylene. Analysis was performed by gas chromatography (GC/FID and GC/ECD).

Results of the testing indicated that concentrations of trichloroethane, and tetrachloroethylene increase approximately two fold when pumping actively. Continuous pumping however does not significantly change the concentration of toluene or xylenes.

There are however, no order of magnitude changes of concentration sampled in components when being actively pumped or naturally vented. The significance of this increase in concentrations would have to be evaluated as to potential health and safety hazards and degree of destruction during flaring.

It is postulated that continuous long term pumping of the landfill gas will reduce the concentrations of the various components to level at or near the passive venting. This postulation is based on the premise that some of the gases extracted from the pumping are from storage and will reduce to the gas production level.

Concentrations and further discussions on the testing can be found in the report entitled "Quantification of Selected Volatile Organics at the Upper Ottawa Street Landfill Site", prepared by Mann and contained in Appendix F of this report.

7.0 LANDFILL GAS CONTROL ALTERNATIVES

As determined by the pumping tests conducted during this project, landfill gas is being produced in the Upper Ottawa Street Landfill Site at significant rates. The landfill gas contains many varied components which are dependent in part on the type of waste deposited in the site area. Analysis of the landfill gas has shown many sulphurous or odour causing components and some potentially harmful components in low concentrations.

As the landfill gas is produced within the site it will either migrate laterally from the site above or below the ground, or build up underneath the cover of the site. When the gas pressure has built up to a high enough degree it will vent naturally through the landfill cover.

Due to the high water table within the site as described by the "Hydrogeological Study Leachate and Gas Impacts Stage (2), Upper Ottawa Street Landfill" conducted by Gartner Lee and Associates Ltd. in September 1980, lateral migration of the landfill gas from the site is of little concern. Natural venting of the landfill gas through the cover soils is suspected due to these high pressures encountered within the site. This is evidenced from the strong odour present at different locations on the

landfill site. The Stone Church Road side of the landfill site appears to have the most noticeable odour problems at this time.

By controlling the natural venting of landfill gas, many problems such as emitting contaminants into the environment and dissipating odours could be reduced and possibly eliminated. There are three main alternatives that have been considered for gas control at the Upper Ottawa Street Landfill Site. These are:

1) Continue to allow the natural buildup of landfill gas beneath the cover and the passive venting of the landfill gas to the environment (do nothing option)
2) Improve the integrity of the cover.
30 Collect and flare the landfill gas from the site.

The following sections illustrate the advantages and disadvantages of each of these alternatives.

7.1 OTPION NO. 1 - DO NOTHING

The "do nothing" option would allow for the continued natural buildup and passive venting of the landfill gas from the site as is presently occurring. The major advantages to this

option are that there is no capital cost and the landfill remains undisturbed.

Ongoing studies performed by others in the immediate area of the site, have not observed high concentrations of hazardous chemicals migrating from the landfill.

The main disadvantage of this option is that nothing would be done to reduce the emissions of potentially hazardous contaminants in the gas or the odour problem at the site.

The natural landfill gas flow or venting rates from the site have not been measured or quantified. However, over the life of gas production at the site, it is postulated that there would be a significant amount of gas vented into the environment. The long term environmental impact from this venting is general unknown.

7.2 OPTION NO. 2 - IMPROVING LANDFILL COVER INTEGRITY

At present, a final cover has been placed over the entire landfill site consisting of silty clay till and waste fines. In the study area

this cap was found to vary from approximately 2 feet to 6 feet in thickness. In some sections of the site, this clay cap has been found to be eroded due to surface water runoff, and the lack of adequate vegetation cover on the site.

The Stone Church Road side of the site is significantly eroded and it is believed that the odours on this section of the landfill may be created by the venting of landfill gas through these eroded sections of the final cover soils and from the goose neck vents attached to the leachate collection system.

The placement of an effective relatively impermeable cover soil would help reduce localized gas emissions and make for a more uniform gas venting over the site. The inherent attenuation capacity of the clay for contaminants within the landfill gas could partially clean the gas as it moves through the cover. However, this is not considered significant over the long term.

This option however, is not a likely solution to the problem of gas emissions as (1) Gas emissions are not eliminated, and (2) There is no guarantee that contaminants will be attenuated in the cover.

Additional disadvantages of this option include the high costs involved, the difficult construction aspects of improving the cap on the site, and no direct control of the gas venting. Many of the highly eroded sections of the site are on very steep slopes. This would make it very difficult (if not totally impractical) for placement and compaction of clay on the slopes to ensure tightness and homogenity of the cover material. It would also be imperative that a sufficient vegetative cover be grown on the recapped area as quickly as possible. If this were not done, the erosional processes again would erode the cover rendering the newly clay capped surface ineffective at controlling the gas venting. Although improving the cover of the site might reduce the volume of landfill gas venting it will not eliminate the venting.

7.3 ALTERNATIVE NO. 3 - COLLECTION AND FLARING

There are two types of collection and flaring systems that could be installed on the landfill site. These are a passive collection and flaring system and an active collection and flaring system. Both of these systems offer a positive measure of gas control on site because both collect the

landfill gas and flare it before it can enter the environment naturally. The flaring as discussed previously, has been shown to be effective in destroying harmful and odour causing components in the landfill gas.

A) PASSIVE COLLECTION AND FLARING SYSTEM

A passive collection system takes advantage of the positive pressure naturally present under the site cover soils to transmit the gas to a flare. A series of wells or perforated pipes laid in gravel trenches are installed on site and provide a low resistance path for the landfill gas to follow. The landfill gas preferentially follows these paths instead of building up underneath and then venting through the cover soils. These wells or trenches are then connected to a flare where the landfill gas vents to the atmosphere and can be burned off.

The major advantage of the passive collection and flaring system is its lower initial capital cost and yearly operation and maintenance cost when compared to an active collection system.

Most passive systems in present use have been installed to help prevent the migration of landfill

gas outside a site boundary. The passive system has not been generally installed as a means of full scale collection of landfill gas.

It would be difficult to ensure that the complete site area could be sufficiently covered with either wells or trenches such that effective landfill gas control could be maintained. Localized venting through the cover would still be a distinct possibility.

With a passive system it would also not be possible to connect all the passive trenches or wells to a singular flare location. Gas nearest to the flare location would be preferentially vented through the flare due to high pressure gradients to atmosphere. Areas outlying the flare location would have smaller pressure gradients to the flare and would not be as easily vented. This could leave areas around the perimeter of the site where venting through the cover instead of into the passive collection system would be the preferential route. The passive system would, therefore, require a number of flare systems around the site area.

Due to the varying landfill gas flow into the system it would also be difficult to ensure proper air to landfill gas ratios for efficient combustion. In addition, the flare assembly must be equipped with a flame arrestor to ensure that no back fire occurs through the landfill gas lines. A flame arrestor creates significant headloss and it is not certain that the natural pressure gradient on site could overcome this headloss and supply enough landfill gas for constant burning.

B) ACTIVE VENTING AND FLARING SYSTEM

An active venting system has the same basic components as a passive venting system. The difference between the two systems is that while a passive system depends on natural landfill gas pressure to transmit the gas through the collection system, an active collection system uses a vacuum pump or blower to produce a negative pressure in the trench or well system to induce gas flow through the collection system.

By using an active system, one can ensure that the area intended for gas control is completely influenced by negative pressure through the control of the pumping rate and vacuum pressure induced in the well.

A single localized flare location for the complete site can also be utilized in this type of system. Efficient flaring can also be produced using this method. The flow of landfill gas into the flare system is always constant as it is set by the pumping rate. Therefore, a set air rate can be used for mixing with landfill gas to ensure efficient burning.

An active venting system has a higher initial capital cost than the passive venting system due to the need for mechanical pumps and motors and the annual operation and maintenance costs are higher.

7.4 DISCUSSION

The first option (Do Nothing) could be implemented on the basis of determining that the present landfill gas emissions and odours are acceptable or there are no feasible alternatives for the control of this landfill gas.

Improving cover integrity (e.g. thicker cover, topsoiling, seeding) would reduce the gas emissions through the cover, odours would be reduced, the site aesthetics improved and would help

reduce water infiltration into the site. The potential for creating underground lateral gas migration the likelihood that neither the attenuation of compounds or the development of an erosion free cover is possible to achieve; and the high capital costs of such an undertaking (considering the steep sided slopes at the site) combine to suggest this option is not feasible.

The most effective way to control gas emissions and odours is to collect and flare the gas. As has been discussed earlier, the flaring of the gas is desirable from an environmental point of view by eliminating odours and decreasing levels of contaminant compounds. The use of a passive venting system may be possible but from preliminary indications appears not to be very practical. The active venting system allows for positive gas control and efficient burning.

Given the above it is therefore recommended that if it is determined by the Upper Ottawa Street Landfill Gas Committee that landfill gas control is required at the Upper Ottawa Street Landfill Site that an active landfill gas system be implemented.

The following sections of the report present a conceptual layout of an active landfill gas venting system and a cost estimate of such a system and recommended implementation procedures.

8.0 ACTIVE LANDFILL GAS COLLECTION AND FLARING SYSTEM DESIGN CONCEPTS

8.1 GENERAL

As discussed in Section 6 it is recommended that if landfill gas control is required at the Upper Ottawa Street Landfill Site the most feasible alternative to implement this gas control is an active gas pumping and flaring system. For the basis of the site design it has been assumed that the complete site requires gas control. This design can be easily amended to phase the installation as required.

The following presents a conceptual design of a landfill gas control system. It should be noted that this design is based only on limited field data and cannot be used for construction. Detailed field testing of the gas wells, spacing, pumping rate, etc. will be required prior to detailed design.

8.2 COLLECTION AND FLARING SYSTEM DESIGN CONCEPT

Map 1 shows a conceptual design of the active collection and flaring system. As can be seen from Map 1, a central pumping and flaring plant location is proposed to be installed in the service

building already existing on-site. From this building two header lines constructed of 8" polyethylene pipe will be placed. One header line is constructed along the southern or Stone Church Road side of the landfill. The second collector is situated on the northern side of the site or the Red Hill Creek side of the landfill.

The typical well as illustrated on Map 1, would be installed using a track-mounted auger drilling rig on the Stone Church Road of the site. As can be seen, these wells are approximately 10 feet deep. This shallow nature should be sufficient to allow a strong negative pressure zone beneath the cover soils. It is estimated from pumping data collected that a well of this depth would need a pumping rate of approximately 10 cubic feet per minute per well to completely cover a 50 foot radius area around the well. Therefore, wells on this section of this site are spaced approximately 100 feet apart. All of these wells are connected to a 4" diameter polyethylene lateral pipe which then leads into the 8" polyethylene header pipe as shown. The lateral pipes would be constructed of 4" polyethylene pipe and are constructed in such a fashion as to drain water that condenses from the landfill gas back into the wells. Polyethylene pipe would be used for all line installations due to its flexibility and its resistance to corrosion. The pipe flexibility will

help prevent breakage problems due to anticipated settlement within the landfill.

The laterals on the Stone Church Road side of the site could be installed using a "Grade-All" or a long boom track-mounted backhoe. Due to the present slope on these sides of the site, exact grading would not be critical and it is anticipated that a constant 2 foot trench could be used for pipe installation. It is not anticipated that any bedding would be required for the laterals or main lines.

Due to the steeper slopes on the Red Hill Creek side of the landfill site it would be very difficult to install laterals or wells down the steep side slope of the site. Therefore, it is proposed to construct wells of the same configuration as on the Stone Church Road side of the site but deeper in depth along the edge of the service roads. These wells are anticipated to be installed in a 2 foot diameter borehole to a depth of between 40 to 50 feet or until water is encountered. It is estimated that a pumping rate of approximately 50 cubic feet per minute per well would be required to create a negative pressure zone of influence approximately 50 foot radius from the wells. However, due to the overlapping of the influence field by adjacent wells it is anticipated

that this cone of influence could be extended up to approximately 100 feet per well. Therefore, well spacing on the Red Hill Creek side of the site would be approximately 200 feet apart.

As was discussed previously, pumping tended to increase some compound concentrations within the landfill gas. However, flaring has been found to be effective at eliminating the odours and harmful components within the landfill gas from this deeper pumping.

8.3 GAS PUMPING AND FLARING SYSTEM

It is proposed that the gas pumping and flaring system be installed in the existing on-site service building. Two separate pumping and flaring systems would be used, one for Stone Church line and one for the Red Hill Creek line.

Low pressure gas pumps would be utilized for pumping of the landfill gas. For control of gas at the Stone Church Road side of the site, it is anticipated that the pump would have to have a flow capacity of approximately 1,600 cfm with a pressure rise of approximately 6 pounds per square inch. The

amount of pumping capacity required depends on the amount of wells installed and the specific area of site where the landfill gas is being produced. If one portion of the site produces gas at greater rates, a higher pumping rate would be required to control the landfill gas. The Red Hill Creek line would have a similar pressure rise with an approximate flow capacity of 1,500 cfm.

Illustrated on Map 1 is a conceptual gas pumping system. This system consists of a centrifugal separator, a particle filter, a pump and a flare. This system would be similar for each line. The centrifugal separator reduces the gas velocity flowing into the pumphouse, which causes water to condense from the gas. This condensate is then proposed to be sewered as shown on Map 1 into the existing leachate collection line, on the eastern boundary of the site. The filter collects particles of greater than 10 microns in diameter and protects the pump impellers from damage. The pump would have to be sized for the flow rate and pressure rise according to the size of the system installed as already discussed. The landfill gas flare would be designed to ensure an air to landfill gas ratio of approximately 1:10 which would ensure efficient combustion and burning of the landfill gas.

9.0 GAS CONTROL PRELIMINARY COST ESTIMATE

An estimated cost for constructing the landfill gas control and flaring system as presented in Section 8 has been calculated. These estimates are considered to be "ball park" and detailed design and costing is required if a gas control system is to be adopted.

Table 9.1 lists estimated unit costs for various phases of the system construction. Table 9.2 lists the estimated costs for the Stone Church Road Gas System and the Red Hill Creek Gas System. A 30 percent contingency has been allowed along with a 20 percent engineering cost.

The total estimated cost for the complete system is estimated at approximately $1,000,000.

9.1 OPERATION AND MAINTENANCE COSTS

Table 9.3 lists estimated operation and maitenance costs for either the Stone Church Road or Redhill Creek system, or for both systems combined. These costs for either system separately are the same due to their roughly equivalent pumping capacities, and therefore their power requirements being approximately equal.

TABLE 9.1

UNIT COST ESTIMATES

1)	WELL CONSTRUCTION (based on typical well as shown on Map 1)	$ 500.00/well
2)	LATERAL LINES (based on 4"Ø polyethylene pipe buttfused and installed)	$ 8.00/foot
3)	MAIN HEADER LINES (based on 8"Ø polythylene pipe buttfused and installed)	$ 10.00/foot
4)	LATERAL LINE CONTROL (based on typical valve as shown on Map 1)	$1,500.00/valve installation

TABLE 9.2

PRELIMINARY COST ESTIMATE
ACTIVE LANDFILL GAS CONTROL SYSTEM

A) STONE CHURCH ROAD GAS SYSTEM

Well, Lateral & Header Construction Costs		
1) Well Construction		$ 80,000.00
2) Lateral Lines (±14,000 ft.)		112,000.00
3) Header Line (±2,300 ft.)		23,000.00
4) Control Valves		60,000.00
	SUB-TOTAL	275,000.00
	±30% Cont.	83,000.00
	±20% Eng.	55,000.00
	TOTAL	$ 413,000.00

Mechanical System Costs		
1) Pump (1,600 cfm capacity)		$ 25,000.00
2) Piping, Valves		10,000.00
3) Centrifugal Separator		3,000.00
4) Fan		2,000.00
5) Flare Assembly		50,000.00
6) Structural Changes to Building		5,000.00
7) Sewer Connection		6,000.00
8) Electrical		10,000.00
	SUB-TOTAL	111,000.00
	±30% Cont.	34,000.00
	±20% Eng.	22,000.00
	TOTAL	$ 167,000.00

TOTAL STONE CHURCH ROAD GAS SYSTEM COST ESTIMATE	$ 580,000.00

TABLE 9.2 (cont'd)

PRELIMINARY COST ESTIMATE
ACTIVE LANDFILL GAS CONTROL SYSTEM

B) RED HILL CREEK GAS SYSTEM

Well, Lateral & Header Construction Costs

1)	Well Construction	$ 62,000.00
2)	Lateral Lines (9,500 ft.)	76,000.00
3)	Header Line (1,800 ft.)	18,000.00
4)	Control Valves	45,000.00
	SUB-TOTAL	201,000.00
	±30% Cont.	60,000.00
	±20% Eng.	40,000.00
	TOTAL	$ 301,000.00

Mechanical System Costs

1)	Pump (1,500 cfm capacity)	$ 25,000.00
2)	Piping, Valves	10,000.00
3)	Centrifugal Separator	3,000.00
4)	Fan	2,000.00
5)	Flare Assembly	50,000.00
6)	Structural Changes to Building*	1,000.00
7)	Sewer Connection*	2,000.00
8)	Electrical*	5,000.00
	SUB-TOTAL	98,000.00
	±30% Cont.	29,000.00
	±20% Eng.	20,000.00
	TOTAL	$ 147,000.00

TOTAL RED HILLCREEK GAS SYSTEM COST ESTIMATE	$ 448,000.00

* Assumes Stone Church Road Line and Pumping System has been installed.

TABLE 9.3

OPERATION AND MAINTENANCE COSTS

ITEM A) STONECHURCH OR REDHILL SYSTEM

1)	Electrical Power 438,000 kwh @ 3.0¢/kwh	± $ 13,200.00
2)	Equipment Replacement and Maintenance 0.16275 x 25,000	± 4,100.00
3)	Manpower 1,095 hr/yr. @ 25.00/hr.	± 27,400.00
	Sub Total	$ 44,700.00
	Miscellaneous = 10%	4,500.00
	TOTAL	$ 49,200.00/year
		± $ 49,000.00/year

ITEM B) BOTH SYSTEMS COMBINED

1)	Electrical Power 876,000 kwh @ 3.0¢/kwh	± $ 26,300.00
2)	Equipment Replacement and Maintenance 0.16275 x 50,000.00	± 8,200.00
3)	Manpower 1,095 hr/yr. @ 25.00/hr.	± 27,400.00
	Sub Total	$ 61,900.00
	Miscellaneous ± 10%	6,200.00
	TOTAL	$ 68,100.00/year
		± $ 68,000.00/year

These costs as listed in Table 9.3, include electrical power, equipment replacement and maintenance, manpower and miscellaneous costs.

Electrical power is based on a 60 H.P. motor at 90% efficiency running constantly, 365 days per year. Electrical costs (including demand charges) are assumed at 3¢/KWH.

Equipment replacement and maintenance costs are based on a 10 year replacement life at a 10% interest rate. Only the pump and motor costs are included in this calculation.

Manpower costs are based on 3 hours per day for the whole year for either or both systems. An hourly rate of 25.00/hr including benefits has been used.

Miscellaneous costs are estimated at 10% of the preceeding item costs per year. The pperation maintenance costs for either Stone Church Road or Redhill Creek system are approximately $49,000 per year. For both combined systems, operation and maintenance costs are approximately 68,000.00/year.

10.0 CONCLUSIONS AND RECOMMENDATIONS

The following conclusions are based on the findings of this report.

1) It has been shown that it is technically feasible to collect and flare landfill gas at the Upper Ottawa Street Landfill Site.

2) The gas is of sufficient combustible quality to burn in a flare. The gas concentration during the pumping tests ranged from 50% to 58% combustible gas (methane) by volume.

3) Initial pressures measured before pumping on the site ranged from 0.14 to 0.62 inches of water. This is high for a landfill site and indicates a high production of landfill gas within the site.

4) Temperatures within the landfill site range from 30°C to 50°C. These are optimum temperatures for landfill gas production as both thermophillic and mesophillic methanogenic bacteria can exist and produce gas at these temperatures.

5) The landfill gas recovery rate from pumping has been estimated to range from 0.3 to 0.9 scf of landfill gas

per pound of refuse per year. This rate is high when compared to typical recovery rates of 0.05 to 0.15 scf/lb/year at other landfills were gas recovery is being conducted.

6) Pumping at deeper depths within the landfill drew gas with higher concentrations of some gas components when compared to component concentrations of landfill gas naturally venting through the gooseneck vents. However, it is postulated that with long term pumping the increased levels will decrease.

7) A 10:1 ratio of air to landfill gas was determined as the most practically efficient burning ratio to optimize flare flame temperature. The flare flame temperature at this ratio was approximately 950°C during testing. An increase of the ratio above 10:1 resulted in little beneficial increase in flare flame temperature.

8) The combustion efficiency for most of the organics quantified was greater than 90% benzene, napthalene, and benzofuran, were destroyed to a lesser degree with combustion efficiencies ranging from 50% to 80%. Styrene benzaldehyde, and methylbenzaldehyde concentrations were very low to begin with, changed very little and may have actually increased. Nitromethane was produced as a by-product of the combustion.

The burning of the landfill gas eliminated the odour, and odour producingj components within the landfill gas.

9) The flaring and combustion of the landfill gas eliminated the odour associated with the landfill gas.

10) If landfill gas control is considered necessary an active collection and flaring system is the most technically feasible system for ensuring positive control of the landfill gas from the site.

11) Preliminary cost estimates for active landfil gas control for the entire landfill would cost on the order of $1,000,000.00. This cost is an approximate cost and further detailed design and costing is required if the project is to proceed.

If it is decided that landfill gas control should be implemented on the Upper Ottawa Street Landfill Site, then the following recommendations are made:

1) The active landfill gas collection and flaring system is recommended as the most technically feasible gas control system for this site. The active system is most likely to should ensure positive gas control over any portion of the site where it is installed.

2) It is recommended that the implementation of an active landfill gas collection and flaring system be phased into operation with the results of each phase being used to refine the design and necessity of the following phases. The following is the recommended implementation procedures:

   a) A long term pumping test be conducted in a test section of the site along Stone Church Road side. This pumping test would entail the installation of at least 3 wells placed at 100 foot spacing with associated pressured monitoring probes. Continuous gas pumping at a rate of approximately 30 cfm and monitoring as required, for at least a one month period. A pumping station and flaring system should be installed for this purpose. This pumping test would provide detailed design data for the gas control system and verify assumptions made in this feasibility study.

   b) After the long term pumping test a detailed design and cost estimate be undertaken. Budgeting for the project be made based on this detailed design and costing.

   c) A phased installation procedure be undertaken such that the first phase would entail the installation

of gas wells, lateral lines along the Stone Church Road side where the most noticeable odour is emitting; the construction of the header line and the installation of the pumping system for the Stone Church Road side gas system. This system should operate for a minimum of one year to determine effectiveness and allow for any revision of the system design for the remainder of the site.

d) The remainder of the Stone Church Road side landfill gas collection system be redesigned (if required) and installed and the Redhill Creek side landfill gas collection and pumping system be redesigned (if required) and installed.

3) It is recommended that the potential for energy utilization from the landfill gas flaring system be reviewed for feasibility. However, it must be recognized that any such energy utilization must not compromise the basic design criteria that the gas system is to control landfill gas emission.

All of Which is Respectfully Submitted,

CONESTOGA-ROVERS & ASSOCIATES LIMITED

Anthony J. Crutcher, P. Eng. Walter Graziani, B.A.Sc.

APPENDIX A

MONITORING DATA

UPPER OTTAWA STREET LANDFILL
HAMILTON ONTARIO
GAS PUMPING TEST

JOB # 906

TECHNICIAN: WG & H.R.
DATE : OCT 20/82
INITIAL CONDITIONS
TIME : 8:10

PROBE #	PRESSURE " H_2O.	CONCENTRATION %	TEMP. °C
GP-1-82. (well)	+0.56	48	54
GP2-82-10	+0.54	64	35
GP2-82-25	+0.36	H_2O	53
GP3-82-10	+0.60	60	31
GP3-82-25.	+0.62	47	42
GP4-82	+0.56	55	32
GP5-82 (VENT)	+0.08	39	18
GP6-82-10	+0.44	50	50
82-20	+0.54	48	43
GP7-82	+0.14	54	35
FLARE	——		

FLARE SAMPLE TAKEN. ☐ YES ☐ NO.

COMMENTS:

UPPER OTTAWA STREET LANDFILL
HAMILTON ONTARIO
GAS PUMPING TEST

JOB # 906

TECHNICIAN: WG & HR

DATE: Oct 20/82
TIME: 10:30

PROBE #	PRESSURE " H_2O.	CONCENTRATION %	TEMP. °C
GP-1-82 (well)	-0.52	49	
GP2-82-10	-0.08	48	
GP2-82-25	+0.38	H_2O	
GP3-82-10	+0.24	60	
GP3-82-25	+0.30	56	
GP4-82	+0.28	56	
GP5-82 (VENT)	+0.10	43	
GP6-82 10	+0.16	46	
25	+0.30	50	
GP7-82	+0.22	65	
FLARE	—	60	[illegible]-480 up to 520

FLARE SAMPLE TAKEN. ☒ YES @10:00 ☐ NO.

COMMENTS: - with good gusts of wind flare temp max. on 528.

UPPER OTTAWA STREET LANDFILL.
HAMILTON ONTARIO
GAS PUMPING TEST

JOB # 906

TECHNICIAN: HWR

DATE : Oct. 20, 82
TIME : 12:00 (Noon)

PROBE #	PRESSURE " H_2O.	CONCENTRATION %	TEMP. °C
GP-1-82. (well)	-0.50	25	
GP2-82-10	-0.13	61	
GP2-82-25	+0.33	H_2O	
GP3-82-10	+0.31	51	
GP3-82-25.	+0.34	48	
GP4-82	+0.28	53	
GP5-82 (VENT.)	+0.03	38	
GP6-82	+0.12 +0.36	10' 45 25' 38	
GP7-82	+0.18	53	
FLARE	——		

FLARE SAMPLE TAKEN. ☐ YES ☒ NO.

COMMENTS:

UPPER OTTAWA STREET LANDFILL.
HAMILTON ONTARIO
GAS PUMPING TEST

JOB # 906

TECHNICIAN: H.R.

DATE: Oct 20 '82.
TIME: 1:30

PROBE #	PRESSURE " H_2O.	CONCENTRATION %	TEMP.°
GP-1-82. (well)	-0.54	40	
GP2-82-10	-0.23	39	
GP2-82-25	+0.39	H_2O	
GP3-82-10	+0.30	63	
GP3-82-25.	+0.31	54	
GP4-82	+0.27	56	
GP5-82 (VENT)	+0.02	42	
GP6-82	+0.04 +0.34	38 43	
GP7-82	+0.16	66	
FLARE	———		

FLARE SAMPLE. TAKEN. ☑ YES ☐ NO.

COMMENTS: @ 1:00 flare sample taken.

UPPER OTTAWA STREET LANDFILL
HAMILTON ONTARIO
GAS PUMPING TEST

JOB # 906

TECHNICIAN: WG.

DATE : Oct 20/82.
TIME : 3:30 P.M.

PROBE #	PRESSURE " H_2O.	CONCENTRATION %	TEMP. °
GP-1-82. (well)	-0.60	36	
GP2-82-10	-0.30	37	
GP2-82-25	+0.36	H_2O	
GP3-82-10	+0.28	58	
GP3-82-25.	+0.32	52	
GP4-82	+0.26	55	
GP5-82 (VENT.)	+0.02	40	
GP6-82	+0.02	42	
	+0.30	40	
GP7-82	+0.18.	58	
FLARE	——	63.	

FLARE SAMPLE TAKEN. ☐ ~~YES.~~ ☒ NO.

COMMENTS: - no flare bags - very very fine smoke @ 4^{00} windy - very difficult to read pressures accurately.

UPPER OTTAWA STREET LANDFILL.
HAMILTON ONTARIO
GAS PUMPING TEST

JOB # 906

TECHNICIAN: HWR

DATE : OCT 20/82
TIME : 5:30

PROBE #	PRESSURE " H_2O.	CONCENTRATION %	TEMP. °
GP-1-82. (well)	-0.59	40	
GP2-82-10	-0.12	75	
GP2-82-25	+0.48	20	
GP3-82-10	+0.24	68	
GP3-82-25.	+0.30	60	
GP4-82	+0.28	70	
GP5-82 (VENT)	+0.08	54	
GP6-82	+0.08 +0.21	62 58	
GP7-82	+0.14	78	
FLARE	—	55	

FLARE SAMPLE TAKEN. ☐ YES ☐ NO.

COMMENTS: ______

UPPER OTTAWA STREET LANDFILL
HAMILTON ONTARIO
GAS PUMPING TEST

JOB # 906

TECHNICIAN: HWR

DATE : OCT 20/82
TIME : 19:30

PROBE #	PRESSURE " H_2O.	CONCENTRATION %	TEMP. °
GP-1-82. (well)		52	
GP2-82-10		60	
GP2-82-25		H_2O	
GP3-82-10		66	
GP3-82-25.		60	
GP4-82		72	
GP5-82 (VENT)		67	
GP6-82		70 63	
GP7-82		90	
FLARE	—	53	

FLARE SAMPLE TAKEN. ☐ YES ☐ NO.

COMMENTS: Too Windy & Rain for Pressures

UPPER OTTAWA STREET LANDFILL.
HAMILTON ONTARIO
GAS PUMPING TEST

JOB # 906

TECHNICIAN: HWR

DATE : OCT. 20/82
TIME : 21:30

PROBE #	PRESSURE " H_2O.	CONCENTRATION %	TEMP. °
GP-1-82. (well)		62	
GP2-82-10		66	
GP2-82-25		H_2O	
GP3-82-10		72	
GP3-82-25		60	
GP4-82		75	
GP5-82 (VENT)		63	
GP6-82		68 63	
GP7-82		85	
FLARE	—	63	

FLARE SAMPLE TAKEN. ☐ YES ☒ NO.

COMMENTS:

UPPER OTTAWA STREET LANDFILL.
HAMILTON ONTARIO
GAS PUMPING TEST

JOB # 906

TECHNICIAN: HR

DATE: Oct 20/82.
TIME: 11:30 p.m.

PROBE #	PRESSURE " H_2O.	CONCENTRATION %	TEMP. °C
GP-1-82. (well)		62	
GP2-82-10		66	
GP2-82-25		H_2O	
GP3-82-10		72	
GP3-82-25.		60	
GP4-82		75	
GP5-82 (VENT.)		63	
GP6-82		68	
GP7-82		63	
FLARE	—	63	

FLARE SAMPLE TAKEN. ☐ YES ☒ NO.

COMMENTS:

UPPER OTTAWA STREET LANDFILL.
HAMILTON ONTARIO
GAS PUMPING TEST

JOB #

TECHNICIAN: WY.

DATE : Oct 21/82
TIME : 2:00 am.

PROBE #	PRESSURE " H_2O.	CONCENTRATION %	TEMP. °
GP-1-82. (well)		64	
GP2-82-10		68	
GP2-82-25		H_2O	
GP3-82-10		70	
GP3-82-25.		60	
GP4-82		70	
GP5-82 (VENT.)		60	
GP6-82		65 64	
GP7-82		82	
FLARE	———	64	640°C

FLARE SAMPLE TAKEN. ☐ YES ☐ NO.

COMMENTS:

UPPER OTTAWA STREET LANDFILL
HAMILTON ONTARIO
GAS PUMPING TEST

JOB # 90

TECHNICIAN: WG.

DATE: Oct 21/82
TIME: 5:30 am.

PROBE #	PRESSURE " H_2O.	CONCENTRATION %	TEMP. °
GP-1-82. (well)	-0.62.	61	
GP2-82-10	-0.30	55	
GP2-82-25	+0.32		
GP3-82-10	+0.14	67	
GP3-82-25.	+0.16	58	
GP4-82	+0.14	65	
GP5-82 (VENT)	+0.04	57	
GP6-82 10	-0.04	57	
20	+0.22	60	
GP7-82	+0.10	82	
FLARE	—	61	

FLARE SAMPLE TAKEN. ☒ YES ☐ NO.

COMMENTS: @ 5:00

UPPER OTTAWA STREET LANDFILL
HAMILTON ONTARIO
GAS PUMPING TEST

JOB # 90

TECHNICIAN: HWR

DATE : Oct 21/82
TIME : 8:00

PROBE #	PRESSURE " H_2O.	CONCENTRATION %	TEMP. °
GP-1-82. (well)	−0.71	60	
GP2-82-10	−0.35	60	
GP2-82-25	+0.30	H_2O	
GP3-82-10	+0.13	67	
GP3-82-25.	+0.16	57	
GP4-82	+0.13	67	
GP5-82 (VENT)	+0.05	60	
GP6-82	−0.07	61	
	+0.16	58	
GP7-82	+0.08	70	
FLARE	—	54	

FLARE SAMPLE TAKEN. ☐ YES ☒ NO.

COMMENTS: ____________________

UPPER OTTAWA STREET LANDFILL.
HAMILTON ONTARIO
GAS PUMPING TEST

JOB # 90

TECHNICIAN: HWR

DATE : OCT. 21/82
TIME : 10:00 AM.

PROBE #	PRESSURE " H_2O.	CONCENTRATION %	TEMP. °
GP-1-82. (well)	-0.74	57	
GP2-82-10	-0.36	55	
GP2-82-25	+0.39	H_2O	
GP3-82-10	+0.10	63	
GP3-82-25	+0.13	54	
GP4-82	+0.10	60	
GP5-82 (VENT)	+0.02	50	
GP6-82	-0.04 +0.16	54 56	
GP7-82	+0.13.	77	
FLARE	———	57	

FLARE SAMPLE TAKEN. ☐ YES ☑ NO.

COMMENTS: ______________________

-adapter - measured flow rate.

UPPER OTTAWA STREET LANDFILL.
HAMILTON ONTARIO
GAS PUMPING TEST

JOB # 90

TECHNICIAN: HR

DATE.: Oct 21/82
TIME: 12:00 Noon.

PROBE #	PRESSURE " H_2O.	CONCENTRATION %	TEMP. °
GP-1-82. (well)	-0.72	60	53
GP2-82-10	-0.34	60	36
GP2-82-25	+0.42	H_2O	54
GP3-82-10	+0.12.	70	31
GP3-82-25.	+0.16	60	42
GP4-82	+0.11	67	32
GP5-82 (VENT)	+0.03	55	11
GP6-82	0.00	62	4
	+0.21	60	4
GP7-82	+0.13	80	36.5
FLARE	—	57	600-720. MOST FREQUEN 640-680

FLARE SAMPLE TAKEN. ☐ YES ☐ NO.

COMMENTS:

UPPER OTTAWA STREET LANDFILL.
HAMILTON ONTARIO
GAS PUMPING TEST

JOB # 906

TECHNICIAN:

DATE: OCT 21/82
TIME: 14:00

PROBE #	PRESSURE " H_2O.	CONCENTRATION %	TEMP. °
GP-1-82. (well)	-0.68	55	
GP2-82-10	-0.24.	45	
GP2-82-25	+0.32	H_2O.	
GP3-82-10	+0.14	68	
GP3-82-25.	+0.12	60	
GP4-82	+0.16	64	
GP5-82 (VENT.)	+0.06	54	
GP6-82	+0.02 +0.20	53 57	
GP7-82	+0.04	75	
FLARE	——	60	

FLARE SAMPLE TAKEN. ☐ YES ☐ NO.

COMMENTS: ______________________________

UPPER OTTAWA STREET LANDFILL.
HAMILTON ONTARIO
GAS PUMPING TEST

JOB # 9

TECHNICIAN: WC ; HL

DATE : Oct 21/82
TIME : 15:30

PROBE #	PRESSURE " H_2O.	CONCENTRATION %	TEMP. °
GP-1-82. (well)	- 0.70	63.	
GP2-82-10	-0.32	57	
GP2-82-25	+0.34	H_2O.	
GP3-82-10	+ .12	70	
GP3-82-25.	+ .18	60	
GP4-82	+0.16	66	
GP5-82 (VENT.)	+0.06	55	
GP6-82	+ 0.02	44	
	+0.16	57	
GP7-82	+0.04	77	
FLARE	———	57	

FLARE SAMPLE TAKEN. ☐ YES ☐ NO.

COMMENTS:

UPPER OTTAWA STREET LANDFILL
HAMILTON ONTARIO
GAS PUMPING TEST

JOB # 906

TECHNICIAN: HR & WG
DATE: Oct 21/82
TIME: 16:30

- AFTER PUMPING STOPPED

PROBE #	PRESSURE " H_2O.	CONCENTRATION %	TEMP. °
GP-1-82. (well)	+0.48	63.	
GP2-82-10	+0.32	65	
GP2-82-25	+0.28	H_2O	
GP3-82-10	+0.42.	74	
GP3-82-25.	+0.42.	63	
GP4-82	+0.36	70	
GP5-82 (VENT.)	+0.06	58	
GP6-82	+ .20 + .42.	35 62	
GP7-82	+0.02.	75	
FLARE	—		

FLARE SAMPLE TAKEN. ☐ YES ☐ NO.

COMMENTS:

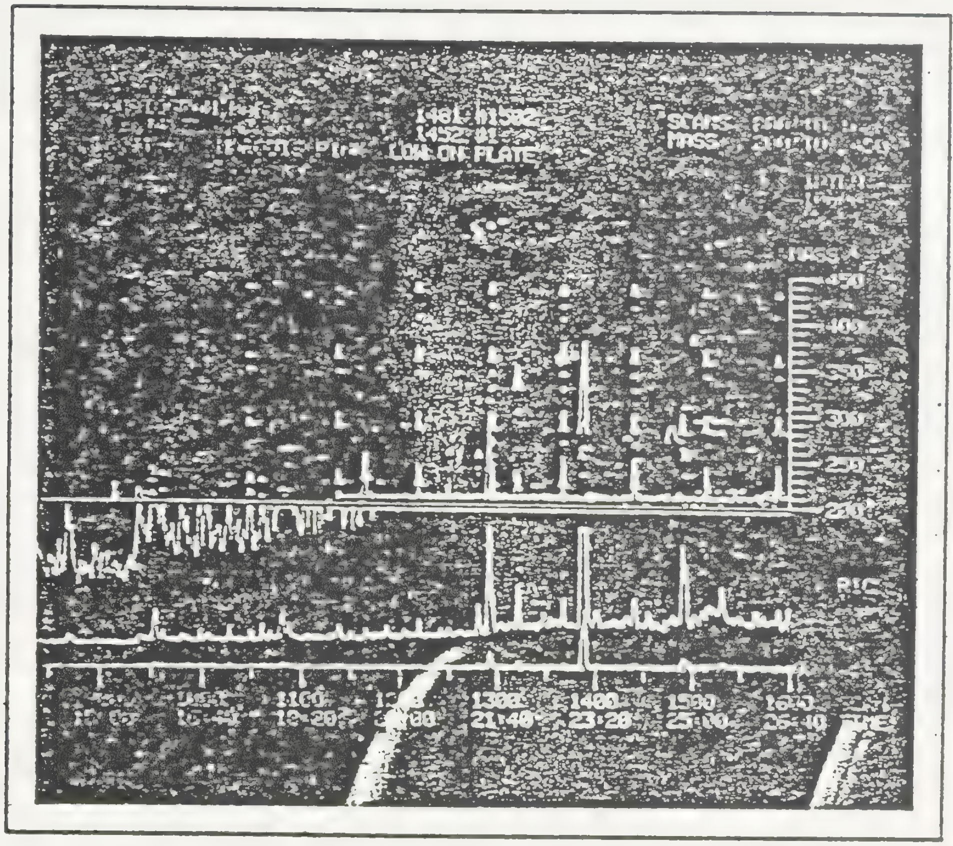
APPENDIX B

MANN TESTING LABORATORIES LTD.

REPORT

"ANALYSIS OF PRE AND POST-FLARE GASES FROM THE TEST WELL ON THE UPPER OTTAWA STREET LANDFILL SITE"

NOVEMBER, 1982



ANALYSIS OF PRE AND POST FLARE GASES FROM THE TEST WELL ON THE UPPER OTTAWA ST. LANDFILL SITE

MANN TESTING LABORATORIES LTD.

PROFESSIONAL
ANALYTICAL SERVICES

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Summary

In order to evaluate the feasability of burning the gases being emitted at the Ottawa Street Landfill Site, a pilot gas flaring project was undertaken by the Ottawa Street Landfill Site Study.

The gas well drilling, as well as the design and construction of the pumping/flaring apparatus was the responsibility of Conestoga-Rovers Associates. The chemical analysis of the pre and post flare gases was performed by Mann Testing Laboratories Ltd.

The main objectives of this experiment were to determine (a) whether the site produced enough methane to maintain a constant burning flare, (b) the degree of destruction of volatile organics contained in the gas, and (c) whether combustion of the gas produced any organics of a toxic or hazardous nature that would be released into the environment.

The first objective was met successfully. It was determined that there is sufficient (40%-60%) methane being produced on site to maintain a constant burning flame.

The second and third objectives were not met with the same success. This was due to an overly rich and hence inefficient flame, as well as location of the sampling probe. Corrective measures are suggested in the text of this report. Chemical analysis of the pre and post flare gases yielded high concentrations (>100 ppm) of acetone, butanone, toluene and xylenes. Chlorinated solvents and hydrocarbons were found in much lower concentration.

Introduction

The analytical work presented here was performed during the period of October 20 to November 12, 1982. This work was requested by Anne Koven and is detailed in our proposal dated October 20, 1982.

The gas was sampled before and after the flare using air bags and tenax tubes. The schedule of sampling was altered slightly due to inclement weather conditions prevailing on October 20, the first day of sampling. The tenax tubes sampled on the first day, for 2 minutes and 5 minutes, were analyzed in the laboratory the same evening. The analysis indicated complete saturation of the 2 minute tubes, thus analysis on the 5 minute tubes was not performed. However, air bag samples taken October 20, were analyzed for volatile organics as well as methane. On October 21, 6 tenax tubes and 6 air bags were used to sample the gas before and after the flare. A summary of the samples taken are listed below.

Tenax Tubes	Pre	Post
October 20 - 1:30 pm	1 (2 min)	2 (2 min)
	3 (5 min)	4 (5 min)
October 21 - 1:00 pm	6 (15 sec)	7 (20 sec)
2:00 pm	8 (10 sec)	9 (20 sec)
3:00 pm	10 (10 sec)	11 (20 sec)

Air Bags (51)	Pre	Post
October 20 - 1:30 pm	A	B
October 21 - 1:00 pm	C	D
2:00 pm	E	F
3:00 pm	G	H

The air bags were filled using an electric, oil-less pump. Although it was not necessary to use the pump on the pre-flare

		Methane (%)	
		Pre	Post
October 20	1:30 pm	42.9	28.3
October 21	1:00 pm	34.6	25.5
October 21	2:00 pm	41.4	44.1
October 21	3:00 pm	44.8	37.1
	Average	40.9	33.9

(c) Tenax Tubes

Quantitation of constituents in the pre and post flaring of the well gas was determined by the air bag analysis, which we feel is a more accurate method of quantitation. However, the tenax tube provides greater sensitivity and allows us to detect lower concentration compounds which would otherwise not be detected by the air bag method. The tenax tubes were, in some instances, saturated with acetone, methyl ethyl ketone, toluene and xylenes. The tenax tube method detected all of those compounds detected by the air bag method. Compounds detected by the tenax tube method and not in the air bag method are listed in table II.

(d) Water Condensate

Approximately 300 mls or organic laden water was collected from a tap located at the bottom of the flare tubing. We decided to analyse this water via concentrator GC/MS to determine its volatile organic content. Two mls of this water were sparged for ten seconds only. (The water was saturated with organics). Analysis of the eluants indicated the presence of those components listed in Tables I and II.

Table 1

AIR BAG ANALYSIS

CONCENTRATIONS OF COMPONENTS IN FLARE GASES IN PPM (v/v)

	Oct 20/82 1:30 pm		Oct 21/82 1:00 pm		Oct 21/82 2:00 pm		Oct 21/82 3:00 pm	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
n-hexane	29	18	23	17	22	17	25	11
dichloroethylene	20	10	16	9	13	12	32	5
acetone	608	533	486	364	453	408	547	261
tetrahydrofuran	17	11	16	11	16	12	16	4
methyl ethyl ketone	154	88	99	61	90	81	92	44
benzene	7	6	8	5	7	7	6	2
toluene	256	133	242	157	244	221	245	64
ethyl benzene	81	40	71	46	79	65	71	28
trichloroethylene	1.4	0.8	1.4	0.5	1.1	0.8	1.2	0.2
1,4 dioxane	10	4	9	4	10	7	5	1
*butene (H/C)	10	5	8	5	6	6	8	5
*butanol	13	6	11	6	9	8	9	3
*hexane (H/C)	9	5	8	5	6	5	8	2
*hexanone (H/C)	90	39	86	41	84	81	58	7
*p-xylene	34	20	51	25	41	37	23	6
*o-xylene	192	105	220	125	205	170	184	61
*m-xylene	84	42	85	58	86	80	86	28
*C_3-benzene	10	2	15	7	19	9	11	2

*approximate concentrations

TABLE II

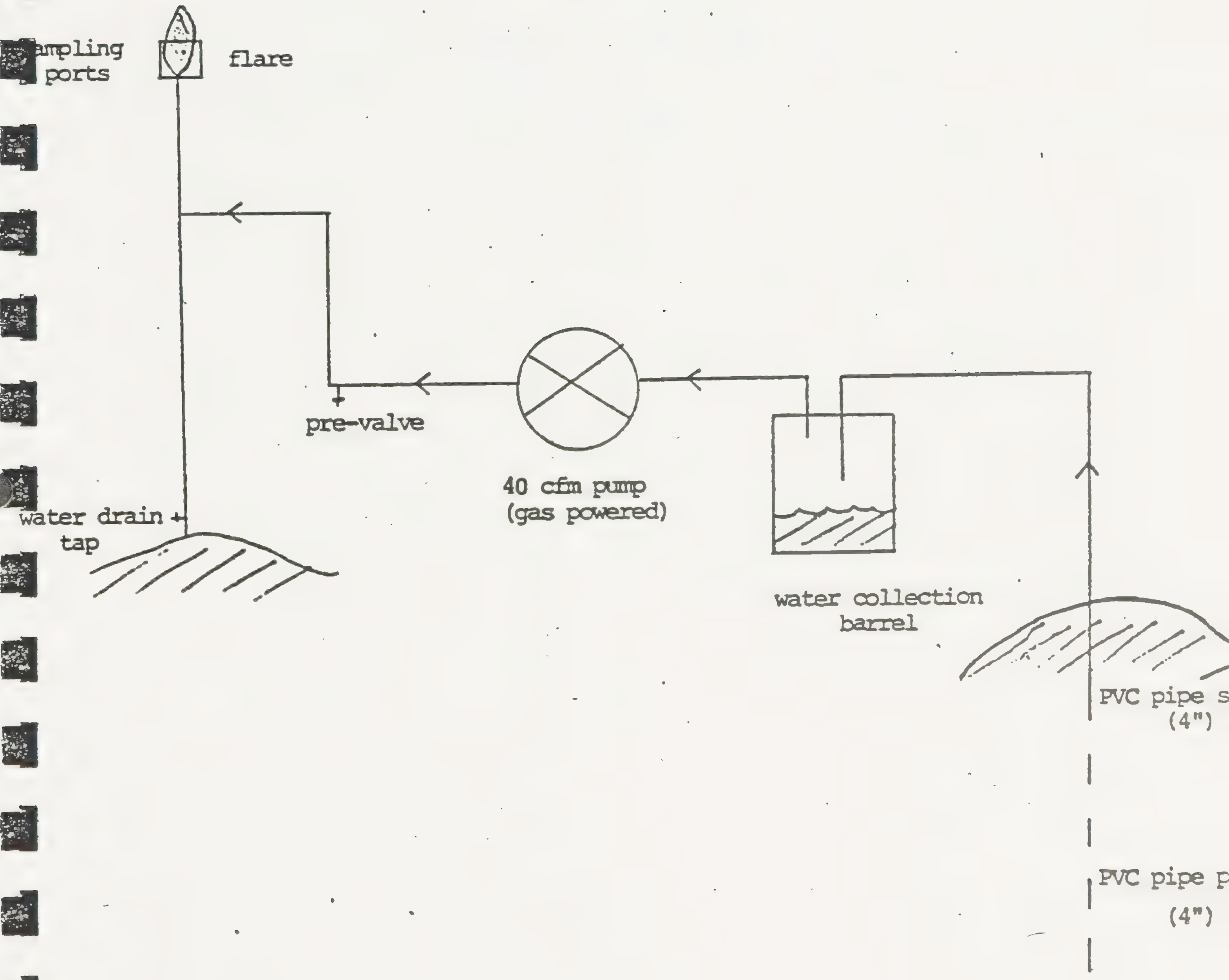
Compounds Detected by Tenax Tubes

- compounds in Table I
- isopropanol
- dichloroethane
- trichloroethane
- many alkyl hydrocarbons
- C_4-benzenes (many isomers)
- C_5-benzenes (many isomers)
- naphthalene (or azulene)
- indene
- methyl indene (many isomers)

* - freon 113
* - styrene
* - methyl styrene
* - benzaldehyde
* - dichloromethane

*Source probably lab contamination.

PIPING SYSTEM OF GAS FLARE



Conclusion

The tenax tube sampling method proved to be too sensitive a method of sampling gases in the flare testing study. The power of the tenax tube method lies in detecting trace quantities of volatile organics. The air bag or gas cylinder sampling methods appear to be better suited to the high organic concentration gases collected from the gas well.

Analysis of the air bags, tenax tubes and water condensate indicates the presence of several volatile organic compounds in relatively high concentrations (i.e. >100 ppm). These are acetone, methyl ethyl ketone, toluene, and xylenes. The well gas also contains significant amounts of alkyl hydrocarbons, chlorinated solvents, low molecular weight alcohols, THF, dioxane, ketones, and C_3-C_5 benzenes.

The initial purpose of this flaring study was to determine the feasability of burning the gas being emitted by the dump site. This objective was not accomplished due to unforeseen miscalculations in the design of the flaring experiment.

The analysis of the tenax tubes and air bags raised certain questions regarding what exactly we were sampling. A two-foot aluminum probe was inserted into the top part of the flare housing containing the flame. The flame however, wavered and extended beyond the top of the flare housing, indicating that we were actually sampling a mixture of heated gas, burning gas and burned gas, as well ambient air that provided the oxygen for the burning process. In order to burn methane efficiently, there must be at least twice as much oxygen present, according to the balanced equation:

Table III

Well gas (l)	Methane(l)	Air(l)	Oxygen (l)	Methane/Oxygen	Ideal ratio
1	0.5	1	0.2	2.5	0.5
1	0.5	2	0.4	1.25	0.5
1	0.5	3	0.6	0.83	0.5
1	0.5	4	0.8	0.63	0.5
1	0.5	5	1.0	0.50	0.5
1	0.5	6	1.2	0.42	0.5
1	0.5	7	1.4	0.36	0.5
1	0.5	8	1.6	0.33	0.5
1	0.5	9	1.8	0.27	0.5
1	0.5	10	2.0	0.25	0.5

In order to insure that enough oxygen is present to completely combust the methane plus organics, a safety factor of extra oxygen should be included which would increase the dilution factor from 5 to 8. Since the concentration of nitrogen (inert) can be measured in the pre and post flare gases, the exact dilution factor can be calculated. The temperature of an efficiently burning methane flame is documented at between 1700 to 2000°C, which is high enough to completely combust almost every compound detected in the gas well. As long as the oxygen is in excess, and the flame temperature exceeds 1500°C, one may assume complete destruction of organics, including chlorinated organics.

Recommendations

The post flare gas sample should contain no methane under optimum conditions. In this case, the tenax tube analysis method could be used to concentrate and detect trace combustion products other than H_2O and CO_2.

In order to evaluate the efficiency of burning as well as the true combustion products, a chimney should be installed that would contain the entire flame.

It has been determined that there is enough methane under the site to maintain a constant burning flare. The first priority of the flaring design should be to ensure that the burning is complete. That is, to ensure that there is an excess of oxygen in the flame, and no methane after the flame. Once these conditions have been determined, analysis of the post flare gases should be undertaken to determine:

(a) if there are any compounds present in the pre-flare gas that are not being burned,

(b) if there are any compounds being formed in the flame, and whether or not, they are of a toxic or hazardous nature.

(c) the concentration of compounds from (a) and/or (b)

APPENDIX C

LITERATURE REVIEW ON LANDFILL GAS PLANNING RESULTS

LITERATURE SEARCH

LANDFILL GAS CONSTITUENTS AND FLARING

December 3, 1982
Reference No. 906

Conestoga-Rovers &
Associates Limited

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REFERENCES

APPENDIX A

1.0 GENERAL

As requested through the Upper Ottawa Street Landfill Site Committee, Conestoga-Rovers & Associates Limited undertook a literature search with respect to the constituents of landfill gas and the effects of flaring the landfill gas on the various constituents.

Over the past few years, Conestoga-Rovers & Associates Limited (CRA) has been extensively involved in landfill gas, initially, from a control prespective and more recently from a recovery and utilization of the gas. In this regard, CRA has compiled much of the available literature on landfill gases. For the purpose of this literature search, the above literature (References 1 to 94) were reviewed with particular emphasis being placed on the landfill gas constituents and the effects of flaring on the constituents.

To augment the above references, the University of Waterloo Library was visited to assess if any more recent documentation was available with respect to the above. No further references were noted with respect to these topics.

The following presents a summary of the more pertinent information obtained from References No. 1 to No. 94.

2.0 LANDFILL GAS STUDIES AND ANALYSIS

Much of the work done with respect to landfill gas has been in conjuction with the recovery and utilization of that gas. Notably, work conducted in California at the Palos Verdes Landfill Site (Reference No. 1, 25, 89), and the Mountainview Landfill Site (Reference No. 10, 18, 66, 88, 94), provide much of the base information. More recently, research projects were conducted at the Fresh Kills Landfill Site in New York (Reference No. 58, 59, 61, 64), and the St. Thomas Landfill Site in Ontario (Reference No. 83, 90, 92, 93).

DeWalle et al, 1978 (Reference No. 15) states that "although methane, carbon dioxide, hydrogen and nitrogen are the main components in the gas phase, other constituents such as argon (0.01% - 0.05%), hydrogensulfide (0.0017% - 0.91%), mercaptan sulfur (0% - 0.33%), sulfides (0.41% - 1.80%), disulfides (0.93% - 1.65%), propane (0.007%), isobutane (0.004%), n-butane (0.006%), isopentane (0.010%), n-pentane (0.014%), hexane (0.128%), heptane (0.292% - 0.45%), octane (0.206%), nonane (0.064%), toluene (0.05% - 0.09%), and benzene (0.08% - 0.11%) can also be present in landfill gases".

Tables 1 to 10 present landfill gas analysis from various landfill sites located across

TABLE 1

TYPICAL LANDFILL GAS COMPOSITION AND CHARACTERISTICS

Component	Component percent (dry volume basis)
Methane	47.5
Carbon Dioxide	47.0
Nitrogen	3.7
Oxygen	0.8
Paraffin Hydrocarbons	0.1
Aromatic & Cylic Hydrocarbons	0.2
Hydrogen	0.1
Hydrogen Sulfide	0.01
Carbon Monoxide	0.1
Trace compounds*	0.5
Characteristic	Value
Temperature (at source)	41°C
High heating value	17727 kJ/std cu m†
Specific gravity	1.04
Moisture content	Saturated (trace compounds in moisture)‡

* Trace compounds include sulfur dioxide, benzene, toluene, methylene chloride, perchlorethylene, and carbonyl sulfide in concentrations up to 50 ppm.

† Landfill gas (as received) from Palos Verdes landfill has HHV of 21646 to 21832 kJ/std cu m (3). Landfill gas (as received) from a Mountain View landfill test well has a HHV of 16420 to 16794 kJ/std cu m with a 20-21 percent nitrogen content by volume (1, 2).

‡ Trace compounds include organic acids(7.06 mg/cu m) and ammonia (0.71 mg/cu m).

Source: Ham et al - (Reference No. 51)

TABLE 2

TYPICAL COMPOSITION OF REFUSE GAS

(@ 320 cfm)

Component	%
Methane	50.2
Carbon Dioxide	48.0
Nitrogen	0.86
Hydrogen	0.19
Oxygen	0.12
Heptane	0.45
Toluene	0.09
Benzene	0.08
Argon	0.01

Source: Dair et al - (Reference No. 8)

TABLE 3

MEASURED GAS COMPOSITION

CONSTITUENT	VOLUME %		
	Avg.	High	Low
Methane	44.03	46.49	41.38
Carbon Dioxide	34.20	36.80	30.73
Nitrogen	20.81	23.51	19.98
Oxygen and Argon ≠	0.96	1.69	0.48
Water	Saturated at 14.7 psia and 90°F		
	grains per 100 ft.^{3}*		
Hydrogen Sulfide		0.40 -	0.91
Mercaptan Sulfur		0.00 -	0.33
Sulfides		0.41 -	1.80
Disulfides and Residuals		0.93 -	1.65

≠ Ar represents at least 50% of the total

* To convert to ppm multiply by 17, 7.63, 6.44 and 4.75 for H_2S, mercaptan, sulfides and disulfides respectively

Source: Blanchet - (Reference No. 88)

TABLE 4

GAS ANALYSIS*
PALOS VERDES SANITARY LANDFILL
(January 31, 1973)

GAS	VOLUME(%)
Methane (CH_4)	52.6
Carbon Dioxide (CO_2)	43.5
Hydrogen (H_2)	0.05
Nitrogen (N_2)	2.92
Oxygen (O_2)	0.29
Argon (A)	0.05
Hydrocarbon (Heptane, C_7H_{16})	0.45
Benzene	0.11
Toluene	0.05
Heat of Combustion (Btu/ft^3)	585

* Withdrawal Rate 320 SCFM

Source: Bowerman et al - (Reference No. 89)

TABLE 5

GAS ANALYSIS*

PALOS VERDES SANITARY LANDFILL
(June 8, 1974)

GAS	VOLUME (%)
Oxygen	0.070
Nitrogen	0.272
Carbon Dioxide	45.588
Hydrogen	0.056
Hydrogen Sulfide	0.0017
Methane	53.283
Ethane	0.000
Propane	0.007
Iso. Butane	0.004
N. Butane	0.006
Iso. Pentane	0.010
N. Pentane	0.014
Hexane	0.128
Heptane	0.292
Octane	0.206
Nonane	0.064
Heat of Combustion (Btu/ft^3)	580
Specific Gravity (gram per cubic centimeter)	1.017

* Withdrawal Rate 320 SCFM

Source: Bowerman et al - (Reference No. 89)

TABLE 6

TYPICAL GAS ANALYSIS

	Mountain View (32 cfm) %V	Sheldon-Arleta (200 cfm) %V
CH_4	52.62	57.88
CO_2	38.16	40.46
N_2	9.01	1.59
O_2 + Ar	0.51	0.07
H_2S	Trace	Trace

Source: Headrick et al - (Reference No. 1)

TABLE 7

COMPRESHENSIVE GAS ANALYSIS BY THE MINISTRY OF THE ENVIRONMENT

Contaminants	GMP 15-78 (9.1 m)	Gas Line
Aliphatic Hydrocarbons (ppm v/v):		
Methane	380 000	560 000
Ethane	66	153
Propane	12	26
n-Butane	10	20
Acrylonitrile	n.d.	n.d.
Aromatic Hydrocarbons (ppm v/v):		
Benzene	1.3	0.84
Toluene	5.8	19.9
o-Xylene	n.d.	n.d.
m-Xylene	2.2	8.2
p-Xylene	0.98	3.9
Ethylbenzene	1.4	4.8
Styrene	1.3	1.2
Cholrinated Hydrocarbon (ppb v/v):		
Chloroform	39	n.d.
Carbon Tetrachloride	n.d.	n.d.
Trichloro-ethylene	108	226
Tetrachloro-ethylene	29	127
Freon II	16	43
Freon 12	1088	1453
Bis (chloromethyl) ether	n.d.	n.d.
Sulphur Compounds (ppb v/v):		
Hydrogen Sulphide	< 8	< 8
Carbonyl Sulphide	< 5	< 5
Carbon Disulphide	< 7	< 7
Methyl Mercaptan	< 27	< 27
Ethyl Mercaptan	163	278

(Reference No. 90)

TABLE 8

BEARE ROAD LANDFILL

APRIL 1978 LANDFILL GAS ANALYSIS

COMPOUND	Concentration (PPM)		
	Vent #1	Vent#2	Ambient Air
CS_2	ND	ND	ND
H_2S	15.5	21.0	ND
Ethyl Mercaptan	0.65	3.2	ND
Methyl Mercaptan	4	ND	ND

Note:

1) ND - Not Detected
2) All analysis by Ministry of the Environment

(Reference No. 91)

TABLE 9

ST. THOMAS LANDFILL SITE, FLUE GAS ANALYSIS

Contaminants	Flue Gas	Gas Line
Aliphatic Hydrocarbons (ppm V/V):		
Methane	9,800	658,000
Ethane	40.8	122
Propane	1.84	21.5
n-Butane	n.d.	n.d.
Pentane	n.d.	Trace
Hexane	n.d.	Trace
Aromatic Hydrocarbons (ppm V/V):		
Ethylene	96.0	30.3
Benzene	1.08	--
Toluene	0.28	5.24
o-Xylene	0.07	0.46
m-Xylene	0.13	1.08
p-Xylene	0.06	0.41
Ethylbenzene	0.04	0.47
Styrene	<0.01	0.02
Chlorinated Hydrocarbons (ppb V/V):		
Chloroform	n.d.	n.d.
Carbon Tetrachloride	1.09	10.9
Trichloro-ethylene	1.86	9.92
Tetrachloro-ethylene	36.7	10.5
Freon 11	9.48	25
Freon 12	8.13	30.1
Methylene Chloride	n.d.	n.d.
Sulphur Compounds (ppb V/V):		
Hydrogen Sulphide	n.d.	n.d.
Carbonyl Sulphide	n.d.	n.d.
Carbon Disulphide	n.d.	n.d.
Methyl Mercaptan	n.d.	n.d.
Ethyl Mercaptan	n.d.	350

n.d. = not detected
All Analysis by Ministry of the Environment

TABLE 10

BEARE ROAD LANDFILL

JULY 1981 LANDFILL GAS ANALYSIS

Compound	Concentration mg/m^3	
	Unflared Landfill Gas	Flared Landfill Gas
Pentane	ND	ND
2.2-Dimethylbutane	ND	ND
Diethyl Ether	ND	ND
2.3-Dimethylbutane	ND	ND
3-Methylphentane	ND	ND
Hexane	ND	ND
2.4-Dimethylpentane	ND	ND
Cyclohexane	9.82	7.36
2.3-Dimethylpentane	3.39	2.26
3-Methylhexane	ND	ND
2.2.4-Trimethylpentane	ND	ND
Heptane	ND	ND
Benzene	ND	ND
Methylcyclohexane	ND	ND
2.3.4-Trimethylpentane	ND	ND
3-Methylheptane	25.2	12.6
Octane	36.9	4.25
Toluene	152.	21.5
Nonane	6.49	0.81
Ethyl Benzene	10.6	1.33
p-Xylene	5.52	0.46
m-Xylene	11.5	1.44
O-Xylene	4.84	0.61
Cumene	ND	ND
Styrene	ND	ND
Decane	41.9	9.17
n-Propylbenzene	ND	ND
o-Chlorotoluene	ND	ND
Mesitylene	ND	ND
p-Cymene	ND	ND
m-Dichlorobenzene	ND	ND
Methylene Chloride	5.71	5.71
Carbon Tetrachloride	ND	ND
Chloroform	ND	ND
Trichloroethylene	9.20	5.82
Bromodichloromethane	ND	ND
Tetrachloroethylene	14.0	14.5
Chlorodibromomethane	ND	ND
COS	21.0	20.0
Methyl Mercaptan	6.2	3.4
Carbon Disulphide	0.3	0.2
Ethyl Mercaptan	13.9	8.7
Hydrogen Sulphide	ND	ND
$(CH_3)_2S_2$	ND	ND
$(CH_3)_2S$	ND	ND
Acrylo-Nitrile	2.6	2.0

NOTE: ND - Not Detected
All analysis conducted by the Ministry of the Environment

(Reference No. 91)

North America. Included with the tables is the source and reference number for the information.

3.0 LANDFILL FLARED GAS ANALYSIS

There is very little documented information regarding the changes in concentration of contaminants before and after the burning or flaring of landfill gas. In the literature, the only published information is with respect to the study conducted at the Fresh Kills Landfill (Reference No. 61). In this study, the flame stability, flame size and shape, gas temperature and flue gas analysis have all been documented. Appendix A presents the pertinent information from this study.

The analysis of flared landfill gas has been conducted at St. Thomas and Beare Road and is presented on Table 9 and Table 10 respectively.

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APPENDIX A

SECTION 3

"EVALUATION OF FRESH KILLS LANDFILL GAS FOR INDUSTRIAL APPLICATIONS"

(REFERENCE NO. 61)

Section 3

TEST PROCEDURES AND RESULTS

COMBUSTION EVALUATION TESTS

The burner was mounted on a pilot-scale test furnace at the IGT Applied Combustion Research Facility and first fired with natural gas. During the initial trials the air/fuel ratio and the furnace cooling tubes were adjusted to provide the proper conditions to simulate a boiler combustion chamber. In this case the air was set to 10% excess air and the cooling tubes were adjusted to absorb approximately 25% of the heat input. After allowing the furnace to reach equilibrium the load was measured to be 21.5% of the heat input. The cooling tubes were left in this configuration throughout all of the subsequent tests. With the furnace at thermal equilibrium the measurements of the flame size and shape, flame temperatures and flue gas analysis were made with the burner firing natural gas. The furnace was then switched to the landfill gas fuel composition, allowed to reach thermal equilibrium and the same measurements were made. Ambient temperature air was used for all tests.

Flame Stability

Both the natural gas and landfill gas exhibited stable flames over a nominal 2 to 1 range of inputs for this burner. The normal turndown for this burner is limited because the input is normally controlled by on-off operation.

Flame Size and Shape

The flame size and shape were measured by analyzing the flame

composition using a water-cooled gas sampling probe. Gas analysis were made at multiple intervals across the furnace. These scans across the furnace width were made at various positions along the furnace length on the flame axis. Analysis of these samples for carbon monoxide and oxygen levels allowed the determination of the flame boundary. This was arbitrarily defined as the region within which 99% of the fuel had been consumed. This boundary corresponds closely to the visible flame boundary. Figures 3-1 and 3-2 show plan views of the flame shapes for natural gas and the landfill gas respectively. Note that the natural gas flame was found to be considerably longer than the landfill gas flame with this burner. This shorter flame for landfill gas is because of the improved fuel/air mixing resulting from the higher fuel injection velocity. The increased velocity results because the volume flow of landfill gas is about twice that of natural gas through the same fuel injectors.

Gas Temperatures

The gas temperatures across the furnace 26 inches (66cm) from the burner wall and in the flue were measured using a suction pyrometer. The measurements made across the furnace are shown in Figure 3-3. The figure compares the measurement for natural gas and the landfill gas. As expected the temperatures and especially the peak temperature for the landfill gas are lower than that found for natural gas. This is due to the carbon dioxide and nitrogen diluents included in the landfill gas which depress the flame temperatures. Although flame temperatures are lower, the landfill gas flame has about a 10% higher emissivity for radiant heat transfer compared to natural gas. The average flame emissivity for the landfill gas and natural gas were calculated to be 0.23 and 0.21 respectively, using the method proposed by Leckner in Combustion

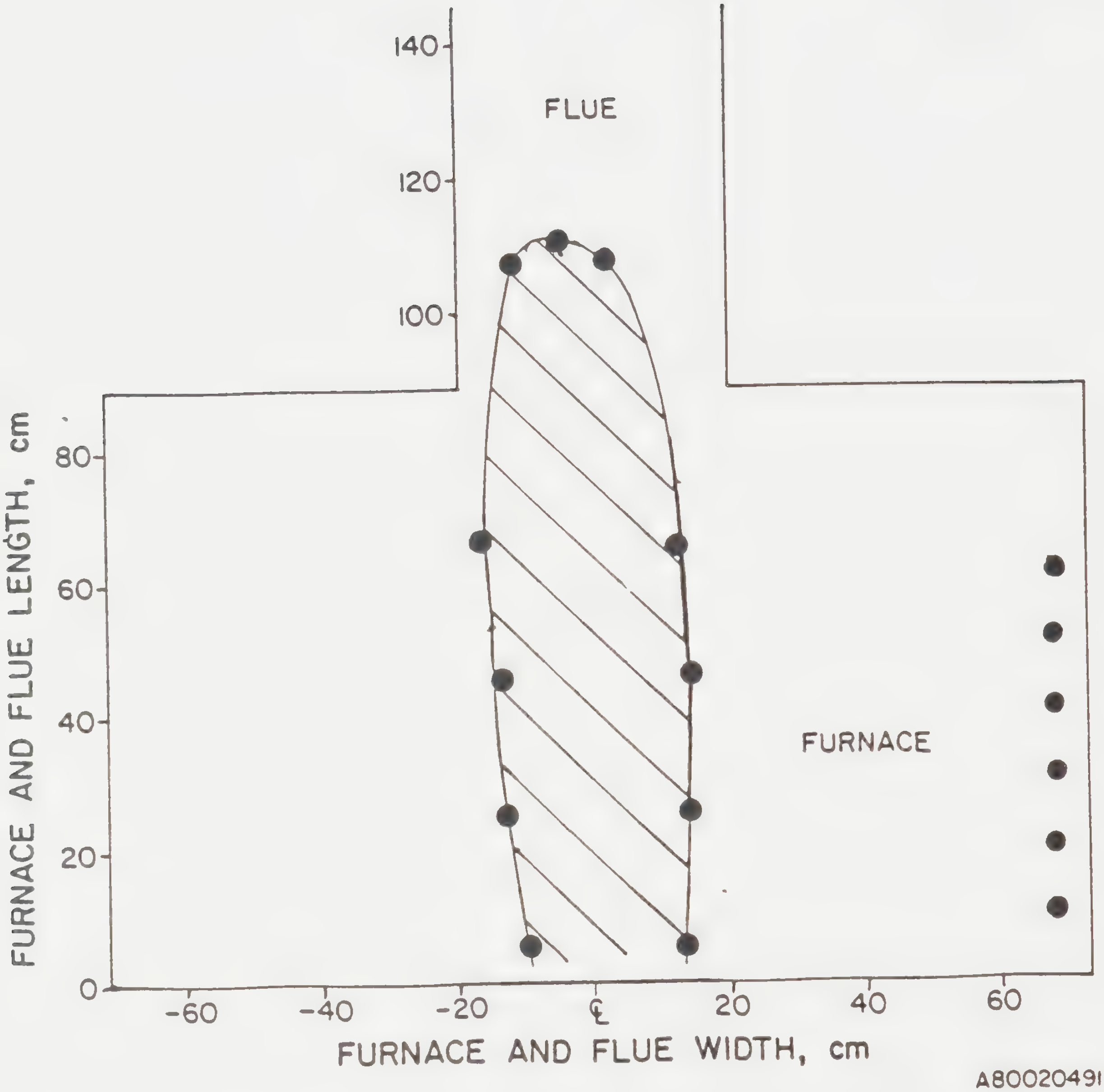


Figure 3-1. Flame Shape for Natural Gas on the Boiler Burner (Plan View)

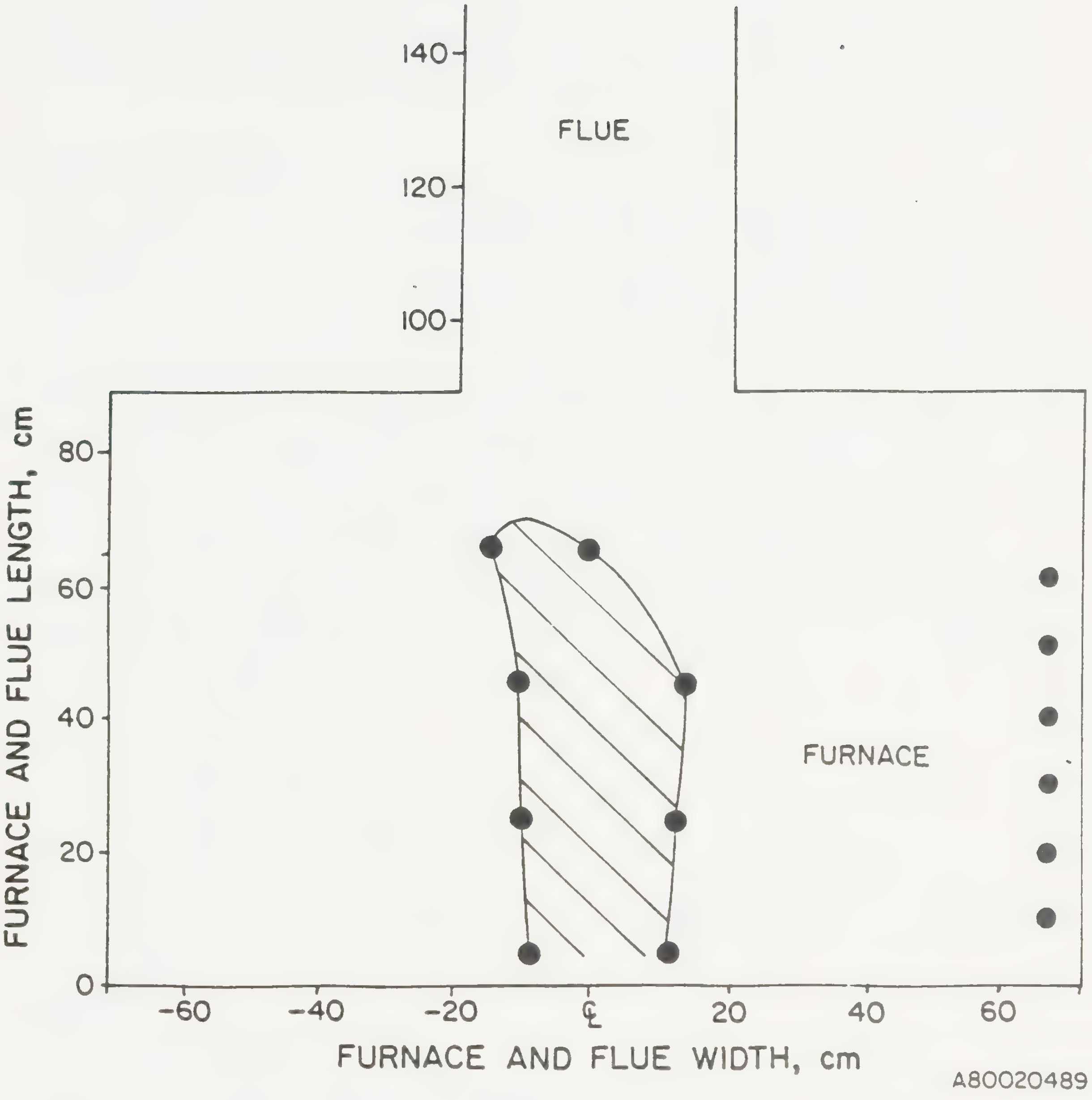


Figure 3-2. Flame Shape for Landfill Gas on the Boiler Burner (Plan View)

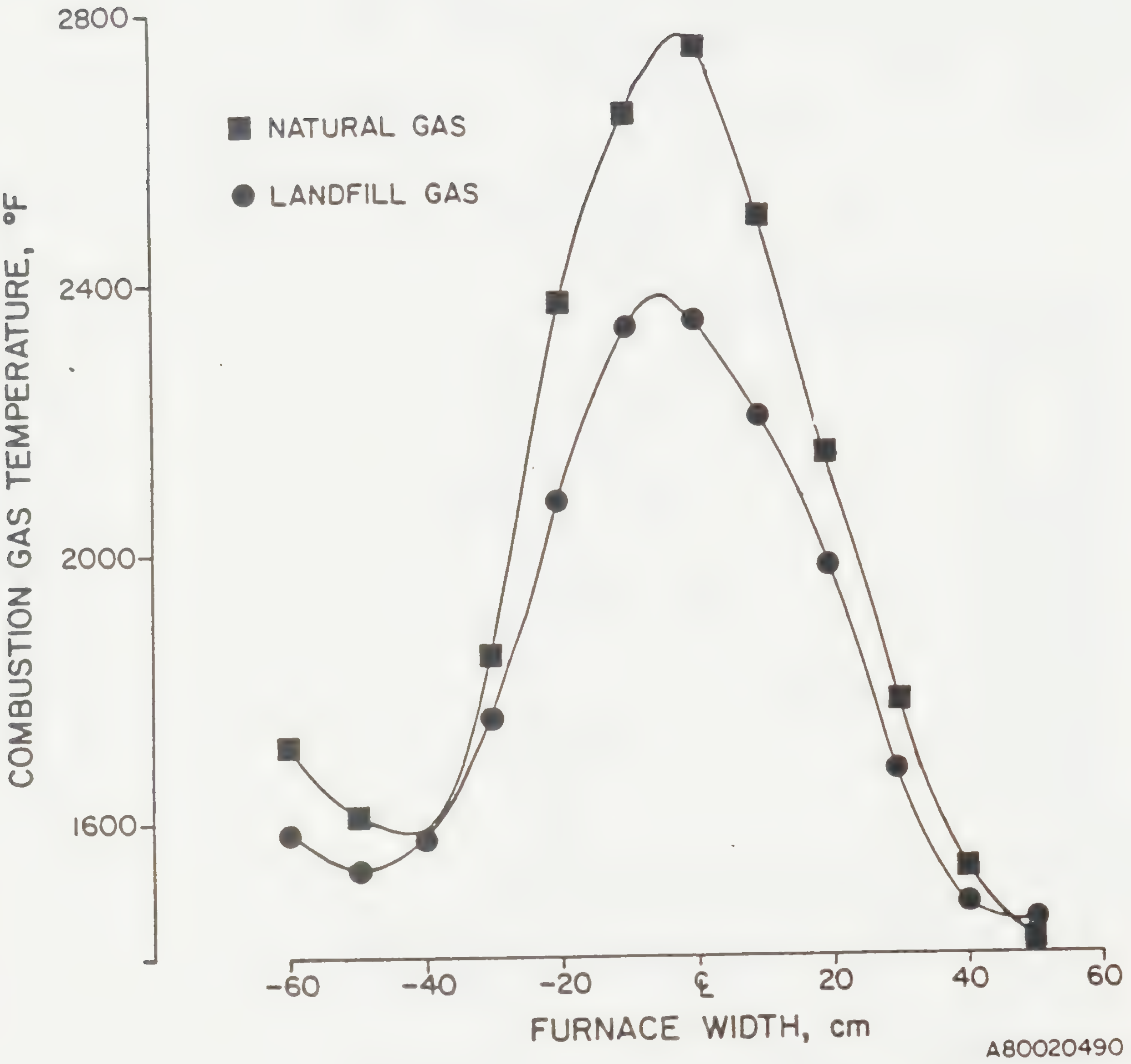


Figure 3-3. Combustion Gas Temperatures Near the Flue

and Flame Volume 19 in 1972. This higher emissivity can partially compensate for the loss in flame temperature.

The temperatures measured in the flue are included in Table 3-1. The flue gas temperature measured for the landfill is about 320°F lower than that measured for natural gas. This is primarily because of the diluents included in the landfill gas.

Thermal Efficiency

The thermal efficiency was defined as the fraction of input enthalpy absorbed by the water-cooling tubes. As described previously the number and placement of cooling tubes was determined during the initial natural gas trials and then the load was left unchanged during all of the subsequent experiments. The thermal efficiency measurements are included in Table 3-1 which describes the furnace operating conditions. The results of the experiments show that under these conditions the two fuels transfer approximately the same amount of heat. In this case the extended flame length may have resulted in a lower than expected thermal efficiency for natural gas.

Flue Gas Analysis

Table 3-1 also contains the results of the flue gas analysis. The oxygen concentrations were adjusted in order to achieve the desired excess air levels. The carbon monoxide level in the flue was high for natural gas due to the long flame length and the level was low for the landfill gas due to the improved fuel/air mixing rates. The lower nitric oxide emissions for the landfill gas are a result of the lower flame temperatures. NO_x formation is a sensitive function of flame temperature, and the presence of inert carbon dioxide in the landfill gas is an effective factor in minimizing the peak flame temperatures.

Table 3-1

FURNACE OPERATING CONDITIONS

						Flue Gas Analysis (Dry)				
Fuel	Firing Rate, 10^6 Btu/hr	Excess Air, %	Flue Gas Temperature, °F (°C)	Flame Length, in. (cm)	Thermal Efficiency, %	O_2, %	CO, ppm	CO_2, %	NO, ppm	NO_2 ppm
Natural Gas	1.0	10	2502 (1373)	43 (110)	21.5 ±0.5	2.0	110	11.2	50	2
Landfill Gas	1.0	10	2181 (1194)	28 (71)	22.5 ±0.5	1.8	70	>15.0	20	0

CORROSION EXPOSURE TESTS

The corrosion tests were conducted at the Fresh Kills Landfill site from September 19, 1979 through October 14, 1979. During this period the metal specimens prepared by the Illinois Institute of Technology Metals Division were exposed to the hot products of combustion of the actual landfill gas for 500 hours. One of the two probe assemblies was maintained at about 900°F (482°C) and the other at about 1150°F (621°C) by internal cooling.

The tests were begun by installing the furnace, pumps, piping and test equipment at the landfill site. Figure 3-4 shows the furnace with the equipment trailer in the background. The furnace was first fired on September 17th and the tests were begun on September 19th. The furnace was fired at about 482 X 10^3 Btu/hr (0.14 MW). The furnace temperature was about 2100°F (1150°C) and the flue temperature was about 1900°F (1040°C). These temperatures varied during the tests due to the changes in ambient conditions caused by the weather. Although the furnace was partially sheltered, the remnants of two hurricanes passed through the area at least partially disrupting the tests.

There were both scheduled and unscheduled shutdowns of the tests. Normal operation was to collect data 24 hours a day with the assistance of Brooklyn Union Gas technical personnel during weekdays and to shutdown on weekends. During the heavy storms that occurred there were additional shutdowns caused by high winds which affected the air pressure safety switch.

The flue gas and fuel were analyzed every two hours using the Teledyne flue gas analyzer and gas chromatograph. In addition, a fuel sample was collected each week and sent to the IGT analytical

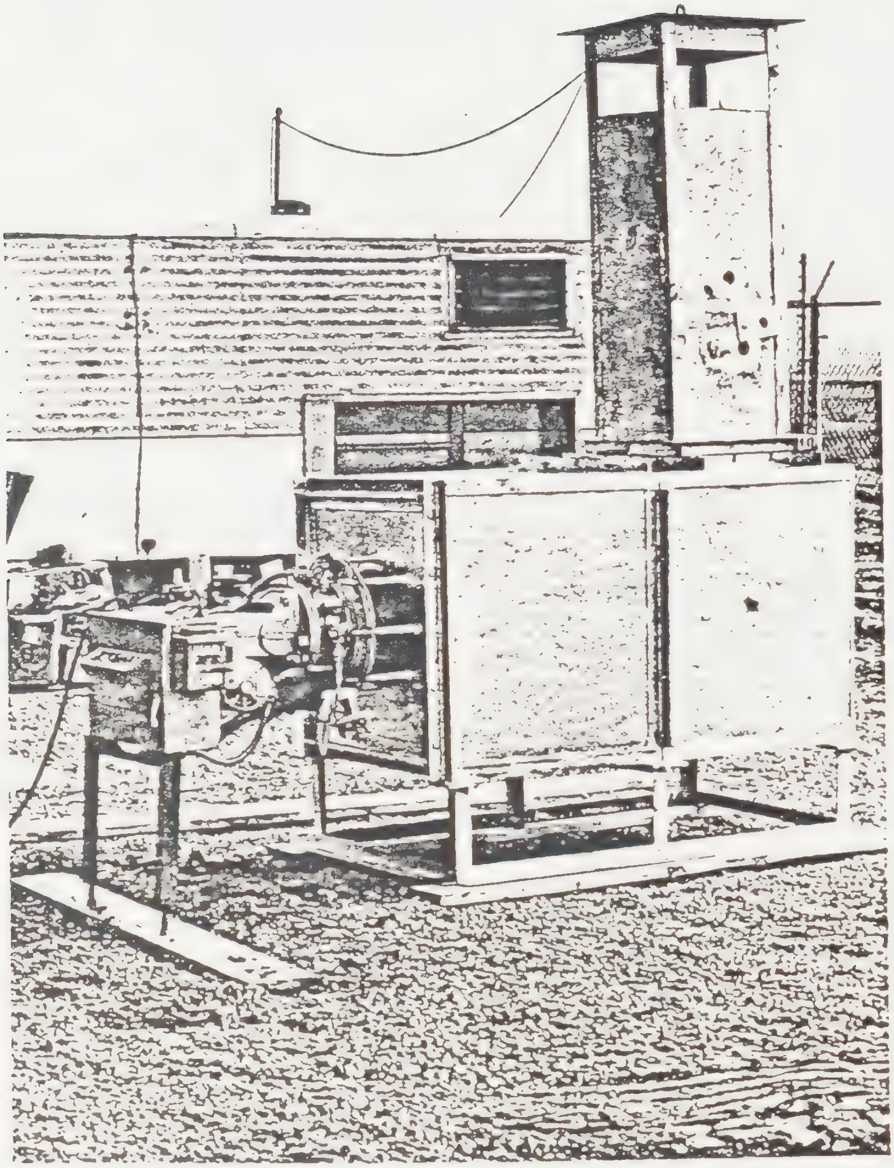


Figure 3-4. Furnace During Installation at the Fresh Kills Landfill Site.

laboratory for a complete analysis, including trace species. The thermocouple measurements of the probe and furnace temperatures were continuously recorded on the multipoint chart recorder.

At the end of the 500 hour exposure period the corrosion probes were returned to the IITRI Metals Division for post exposure evaluation.

Appendix C gives a compilation of the data that was recorded regarding the furnace operating conditions and Appendix D is a compilation of the onsite fuel analysis data. These data provide the information regarding the conditions to which the metallic specimens were subjected. The daily average values from Appendix C were given to IITRI Metals Division for their post exposure corrosion evaluation.

Tables 3-2 through 3-6 give the results of the fuel analysis conducted by the IGT analytical laboratory. Tables 3-2 through 3-5 show the major components found in the four samples while Table 3-6 shows the concentrations of the chloro- and fluorocarbons that were identified in the samples. Analysis of the trace species data shows that the chlorine atom concentration varied from 2.1 to 23 ppm with an average value of 13 ppm. The fluorine atom concentration varied from 1.4 to 14 and averaged 10 ppm. The first sample, which was taken two days after the start of the experiments, showed the lowest trace species concentrations and the later samples all showed significantly higher concentrations.

The post exposure corrosion analysis was conducted by the IITRI Metals Division and a complete description of their procedures

Table 3-2

MASS SPECTROMETER ANALYSIS OF FRESH KILLS LANDFILL GAS SAMPLE
TAKEN ON SEPTEMBER 21, 1979
(Extraction Rate @ 50 CF/min from Test Well No. 2)

Species	Mole %	Species	Mole %
Air (Free)	0.00*	Ethylene	0.00
Hydrogen Sulfide	0.00	Propylene	0.00
Nitrogen	3.60	Butenes	0.00
Carbon Monoxide	0.00	Pentenes	0.00
Oxygen	0.20	Hexenes	0.00
Carbon Dioxide	38.40	Heptenes	0.00
Hydrogen	0.00	Butadiene	0.00
Argon	0.04	Pentadiene	0.00
Helium	0.00	Cyclopentadiene	0.00
Methane	57.80	Acetylene	0.00
Ethane	0.00	M.Acet./Propadiene	0.00
Propane	0.00	Benzene	0.00
N-Butane	0.00	Toluene	0.00
I-Butane	0.00	Xylene	0.00
Pentanes	0.00	Ethyl Benzene	0.00
Hexanes	0.00	Styrene	0.00
Heptanes	0.00	TOTAL	100.04

* Not found, less than 0.01% given as 0.00.

Table 3-3

MASS SPECTROMETER ANALYSIS OF FRESH KILLS LANDFILL GAS SAMPLE TAKEN ON SEPTEMBER 29, 1979

(Extraction Rate @ 50 CF/min from Test Well No. 2)

Species	Mole %	Species	Mole %
Air (Free)	0.00*	Ethylene	0.00
Hydrogen Sulfide	0.00	Propylene	0.00
Nitrogen	2.40	Butenes	0.00
Carbon Monoxide	0.00	Pentenes	0.00
Oxygen	0.00	Hexenes	0.00
Carbon Dioxide	39.40	Heptenes	0.00
Hydrogen	0.00	Butadiene	0.00
Argon	0.00	Pentadiene	0.00
Helium	0.00	Cyclopentadiene	0.00
Methane	58.20	Acetylene	0.00
Ethane	0.00	M.Acet./Propadiene	0.00
Propane	0.00	Benzene	0.00
N-Butane	0.00	Toluene	0.00
I-Butane	0.00	Xylene	0.00
Pentanes	0.00	Ethyl Benzene	0.00
Hexanes	0.00	Styrene	0.00
Heptanes	0.00	TOTAL	100.00

* Not found, less than 0.01% given as 0.00.

Table 3-4

MASS SPECTROMETER ANALYSIS OF FRESH KILLS LANDFILL GAS SAMPLE TAKEN ON OCTOBER 5, 1979

(Extraction Rate @ 50 CF/min from Test Well No. 2)

Species	Mole %	Species	Mole %
Air (Free)	0.00*	Ethylene	0.00
Hydrogen Sulfide	0.00	Propylene	0.00
Nitrogen	1.10	Butenes	0.00
Carbon Monoxide	0.00	Pentenes	0.00
Oxygen	0.00	Hexenes	0.00
Carbon Dioxide	39.70	Heptenes	0.00
Hydrogen	0.00	Butadiene	0.00
Argon	0.00	Pentadiene	0.00
Helium	0.00	Cyclopentadiene	0.00
Methane	59.20	Acetylene	0.00
Ethane	0.00	M.Acet./Propadiene	0.00
Propane	0.00	Benzene	0.00
N-Butane	0.00	Toluene	0.00
I-Butane	0.00	Xylene	0.00
Pentanes	0.00	Ethyl Benzene	0.00
Hexanes	0.00	Styrene	0.00
Heptanes	0.00	TOTAL	100.00

* Not found, less than 0.01% given as 0.00.

Table 3-5

MASS SPECTROMETER ANALYSIS OF FRESH KILLS LANDFILL GAS SAMPLE TAKEN ON OCTOBER 14, 1979

(Extraction Rate @ 50 CF/min from Test Well No. 2)

Species	Mole %	Species	Mole %
Air (Free)	0.00*	Ethylene	0.00
Hydrogen Sulfide	0.00	Propylene	0.00
Nitrogen	1.80	Butenes	0.00
Carbon Monoxide	0.00	Pentenes	0.00
Oxygen	0.10	Hexenes	0.00
Carbon Dioxide	39.00	Heptenes	0.00
Hydrogen	0.00	Butadiene	0.00
Argon	0.01	Pentadiene	0.00
Helium	0.00	Cyclopentadiene	0.00
Methane	59.10	Acetylene	0.00
Ethane	0.00	M.Acet./Propadiene	0.00
Propane	0.00	Benzene	0.00
N-Butane	0.00	Toluene	0.00
I-Butane	0.00	Xylene	0.00
Pentanes	0.00	Ethyl Benzene	0.00
Hexanes	0.00	Styrene	0.00
Heptanes	0.00	TOTAL	100.01

* Not found, less than 0.01% given as 0.00.

Table 3-6

ANALYSIS FOR TRACE HALOCARBONS IN FRESH KILLS LANDFILL GAS SAMPLES (Extraction Rate @ 50 CF/min from Test Well No. 2)

Component	Sample Date			
	9/21/79	9/29/79	10/5/79	10/14/79
	Concentration, ppm (± 10%)			
Freon-11 $CFCl_3$	--*	--	--	--
Freon-12 CF_2Cl_2	0.4	4.3	2.9	4.1
Freon-13 CF_3Cl	--	--	--	--
Freon-21 $CHFCl_2$	--	0.2	0.1	0.2
Freon-22 CHF_2Cl	0.1	1.0	0.6	0.8
Freon-23 CHF_3	--	--	--	--
Freon-113 CCl_3-CF_3	0.04	0.2	0.1	0.4
Freon-114 CF_2Cl-CF_2Cl	0.08	0.6	0.4	0.7
Dichloromethane	0.01	0.2	0.4	0.09
Trichloromethane	--	2.2	--	--
Tetrachloromethane	--	--	--	--
Chloroethylene	0.04	0.3	0.2	0.2
Dichloroethylene	0.2	1.1	0.7	0.9
Trichloroethylene	0.07	0.2	0.2	0.3
Tetrachloroethylene	0.06	0.3	0.2	0.2
Total Halocarbons Found	1.0	10.6	5.8	7.9
Total F Atom Conc.	1.4	14.0	9.0	14.0
Total Cl Atom Conc.	2.1	23.0	11.0	16.0

* Not found, generally less than 0.2 ppm.

Note: All samples contained trace Hydrocarbons in $C_2 - C_8$ range at 1 – 10 ppm levels.

and results is included in Appendix A. The major result of their analysis is that there was no evidence of corrosion from the chlorine and fluorine species in the flue gases. The only type of corrosion detected was simple oxidation on the carbon steel, 2-1/4 Cr — 1 Mo and 5 Cr — 1/2 Mo alloys. The 310, 316, RA-333 and aluminized carbon steel showed no evidence of corrosion. Simple oxidation is due to the exposure of these metals to oxidizing conditions and high temperature. This oxidation would occur regardless of the type of fuel used under these conditions.

A surprising finding was the discovery of a powdery deposit on the samples containing silicon, antimony, lead, copper, nickel and scandium. Some of these deposits were traced to the demister pad in the entrainment separator in the fuel piping system. The pad was polypropylene and weighed 9 lb. It contained 1/10 of 1% antimony. The support ring was 316 stainless steel, weighed 12 lb., and contained 1/10 of 1% silicon and 19% nickel. A copper coupon was placed in the line and may account for the copper found. The source of the trace amounts of lead and scandium is still not determined.

In-Line Corrosion Test

During this phase of the test, and during the previous pumping, four coupons were placed in the landfill gas fuel piping. The four coupons were composed of cast iron, high density polyethylene, API 5L carbon steel, and copper.

These coupons, manufactured by Cosasco of California, measured 3-7/32 inches (81.75 mm) long, 1/2 inch (12.7 mm) wide, and 1/16 inch (1.6 mm) thick. All four coupons were preweighed by the manufacturer prior to packaging and installing in the gas stream.

Each coupon represented a standard gas pipeline material. The four coupons were placed in the gas stream and exposed to total flow of approximately 1.9 million cubic feet (5.7 X 10^4 m^3) of landfill gas.

At the completion of the burner test, these coupons were removed from the gas stream and then reweighed by the Brooklyn Union Gas laboratory. Table 3.7 shows the results of these samples.

Table 3-7

Corrosion Coupon Weights

Sample	Weight Before Testing	Weight After Testing	Difference
Cast Iron	14.6554 g	14.6864 g	+ 0.031 g
Copper	12.7006 g	12.2760 g	- 0.4246 g
Carbon Steel	11.6190 g	11.6380 g	+ 0.019 g
Polyethylene	1.4436 g	1.4284 g	- 0.0154 g

Using the methods outlined in the 1979 American Society for Testing and Materials (ASTM) annual book of standards, the corrosiveness of the landfill gas can be estimated. However, only one of the metals (copper) demonstrated a weight loss. The corrosion rate for copper was calculated as 0.034 mils penetration per year.

Several discrepancies were encountered when the manufacturer's specified weights of unused samples were checked by the Brooklyn Union Gas laboratory. Many of the sample weights were found to be higher than the manufacturer's weights. Because of these discrepancies, the results of this test may not be valid.

To accurately determine the corrosion rates of copper, steel, cast iron, and polyethylene, the samples would have to be first weighed and then placed in a landfill gas stream.

Fortunately, this can be accomplished at Fresh Kills during an upcoming project.

This project entails operating a 100 kW engine generator set for 1 year. During this project a new set of coupons will be installed and will remain in the line through project completion.

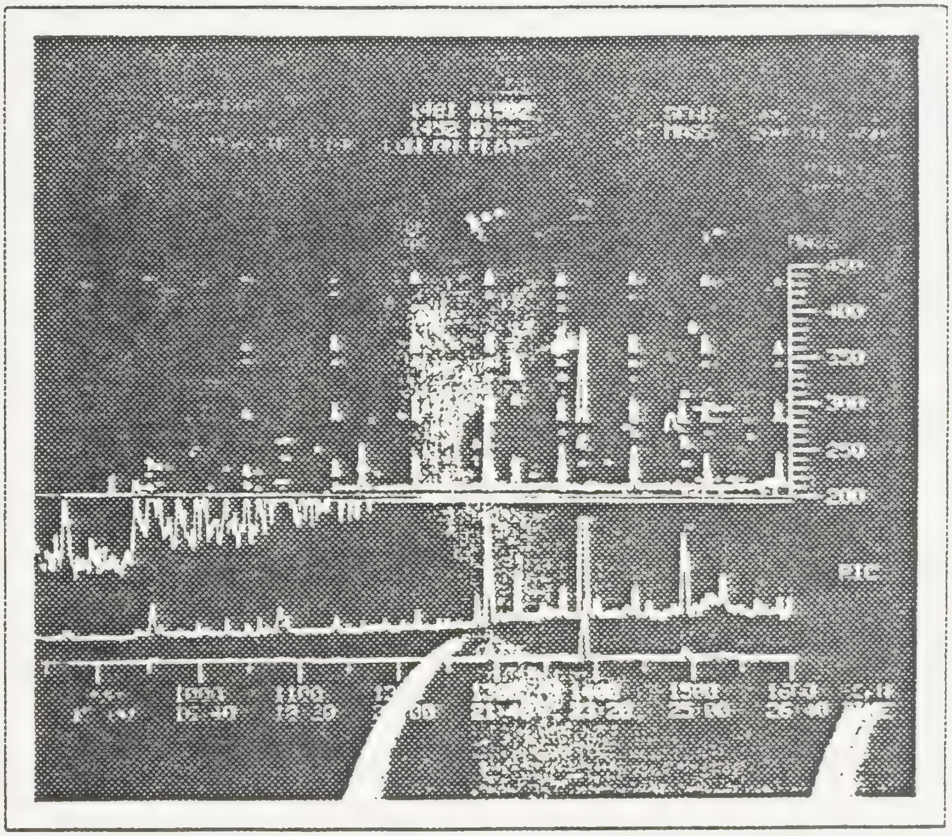
A report, which will include data on the corrosion rates of the aforementioned materials, will be issued by the New York State Energy Research and Development Authority by September 1981.

APPENDIX D

MANN TESTING LABORATORIES LTD.

CHEMICAL ANALYSIS OF PRE AND POST-FLARE CASES

JANUARY 31, 1982



CHEMICAL ANALYSIS OF PRE AND POST FLARE GASES

SUBMITTED TO

A. KOVEN, RESEARCH DIRECTOR

UPPER OTTAWA STREET LANDFILL STUDY

JANUARY 31, 1983

MANN TESTING LABORATORIES LTD.

PROFESSIONAL
ANALYTICAL SERVICES

Summary

A gas recovery and flaring study was undertaken to determine the feasability of burning the landfill gas at the Upper Ottawa Street Landfill Site. The first study determined that the gas must be diluted with air in order to achieve an efficient flare. The ratio of 10:1 (air:landfill gas) was determined as the optimum mixture. A maximum flame temperature of 950°C was recorded under these conditions. Combustion efficiency of organics and chlorinated organics was measured at greater than 90 percent for most compounds. Benzene, naphthalene and benzofuran have lower combustion efficiencies, however this may be due to actual formation of these compounds in the flame. Incomplete oxidation of alkyl aromatics resulted in increased levels of styrene, benzaldehyde and methyl benzaldehyde. Nitromethane was produced in significant quantities.

Introduction

This work is the second part of the study to determine the feasibility of burning landfill gas at the Upper Ottawa Street Landfill Site. The work was requested by Anne Koven, Research Director, of the Upper Ottawa Street Landfill Committee.

The first flaring study determined several important parameters. The composition of the undiluted landfill gas was determined to be approximately 50% methane, 35% carbon dioxide, 10% nitrogen and 3% oxygen. Theoretically this concentration of hydrocarbon supports combustion and the pilot flare apparatus proved this experimentally, although the flame was poor.

Analysis of the pre and post flare gases during the first study indicated that combustion was not complete. High concentrations of methane were detected in the post flare gas samples. The flame extended up to 50 feet above the chimney. The conclusions from the first study were that combustion was incomplete due to an overly fuel rich flame. It was obvious that in order to burn the landfill gases efficiently, it was necessary to introduce oxygen into the system so that the minimum oxygen to methane ratio was 2:1 according to the balanced equation 1:

$$CH_4 + 2O_2 - CO_2 + 2H_2O \qquad \text{(eq. 1)}$$

The flaring apparatus was modified by Connestoga-Rovers Associates to allow dilution of the landfill gas (LFG) by ambient air. The minimum air:LFG ratio required to satisfy eq. 1 was 5:1. The chimney was also extended in order to contain the flame, and provide better sampling.

In this, the second part of the flaring study, the first day was spent determining the air:LFG ratio that would optimize combustion efficiency of the volatile organics, including methane. Three ratios of air:LFG were set up at 5:1, 7:1 and 11:1. The temperatures at various heights in the chimney were recorded at each ratio setting, and the results, as obtained by Conestoga-Rovers are listed in Table 1. Post combustion gases were collected at each setting and were analysed for constituent gases. The results of the analysis indicated a slightly higher level of residual methane in the 5:1 sample than the 11:1 sample. This fact, plus the higher temperatures recorded at the 11:1 setting led us to choose 10:1 as the ratio of air:LFG upon which we would perform more extensive sampling and analysis.

On the second day, pre and post combustion samples were taken in gas bags, tenax sorbent tubes and gas cylinders pressurized to 90 psi. The temperatures were measured at 10:1 amd 20:1 and are listed in Table 1.

The objectives of sample analysis for trace organics in the second study were to determine (a) the degree of destruction of LFG organics by the flame, and (b) whether any toxic or hazardous compounds were being formed in the flame.

Methods and Analysis

A teflon oil-less vacuum/compressor pump was used to draw gases through the tenax sorbent tubes and to fill the gas bags and cylinders. A twenty foot length of 1/4 inch copper tubing was used to sample the hot gases in the chimney. The sorbent tubes were placed in-line before the pump, and the bags and cylinders after the pump for sampling.

The tenax sorbent tubes were thermally desorbed in the Unacon 780B Concentrator (Envirochem) equipped with a 30M DB-1 fused silica capillary column. The total ion current chromatograms are included in Appendix A. The eluants were analysed by mass spectrometry on a Finnigan 4500 equipped with the Incos data system. All EI spectra were obtained at 70 eV.

A Hewlett-Packard 5700 GC/ECD was used to screen the gas samples for halogenated compounds using Poropak Q and OV-1 columns.

An Antek GC/TCD with a sampling loop was used to quantify the concentrations of CH_4, O_2, N_2 and CO_2 using Molecular Sieve 5A and Carbosieve B columns.

A Hewlett-Packard 5840 equipped with automatic valves and several columns, specially designed for gas analysis, was used to screen for the C_1-C_3 hydrocarbons.

Comment on Thermal Desorption Mass Spectrometry (TDMS)

The analysis of organics in air is not a new science. Industrial Hygienists conduct many such studies as a daily routine and have very specific methodology. Fortunately they know what substances to monitor prior to analysis.

Such is not the case for the Upper Ottawa Street Landfill Gas Flaring Study. Our work to date has been a valuable guide as to the kinds of volatile compounds that one might expect in the gas leading to the flame. Very little could be predicted as to the composition of the post flare gas.

Thermal desorption mass spectrometry was recommended as a viable technique[1,2,3] although its shortcomings were understood. For example, highly volatile compounds could not be quantitatively retained on solid sorbents if the sampling volume was very high; while non-volatile compounds, such as benzo (a) pyrene, which exist in the atmosphere at concentrations lower than volatile compounds, generally could not be detected analytically without very high sampling volumes. This study used relatively low sample volumes and thus PAH compounds are unlikely to be found. Another problem is that reactive compounds, such as styrene and ethylene oxide, which tend to polymerize on active surfaces, were more effectively retained on sorbents which had relatively more active surfaces. These paradoxes indicate areas where compromises would be required to obtain a single sampling system. Our professional judgement indicated that the selection of tenax/ambersorb/charcoal and a DB-1-Capillary column system would analyse the range of compounds deemed necessary for this phase of study.

Results

The gas bag and cylinder samples were used to analyse for the constituent gases via GC/TCD, GC/ECD and GC/FID. These results are listed in Table II. The combustion efficiency for methane and 1,1,1 trichloroethane is greater than 95%. There does, however, appear to be an increase in the C-2 hydrocarbons after burning.

The results of the sorbent tube analysis by GC/MS are listed in Table III, which lists only those compounds detected in relatively high concentration in the post combustion gases. The concentrations listed are approximate due to the terms of reference of this study and the variability of the sorbent tube method. The absolute values, based on the response of toluene, are not as meaningful as the relative concentrations. The combustion efficiency of toluene, ethyl benzene, xylenes, C_3-benzenes, C_4 benzenes, indenes and dichlorobenzene is greater than 90%. The combustion efficiency of benzene, benzofuran, and naphthalene is less than 90%, while styrene, nitromethane, benzaldehyde and methyl benzaldehyde all increase in concentration. The presence of nitromethane is based on the EPA/NIH library and has been confirmed. Dimethylnitrosamine was not detected in either the pre or post combustion samples. The sorbent tube method would detect dimethylnitrosamine if it were present above 50 ppb. The concentration of alkyl hydrocarbons, alcohols, aldehydes and ketones dropped dramatically in the post flare samples, with greater than 90% combustion efficiency.

TABLE 1

TEMPERATURE PROBE READINGS (°C)

DIFFERENT AIR TO LFG RATIOS

	Day 1			Day 2	
Ratio	4:1	7:1	11:1	10:1	20:1
Top Port	300	N/A	N/A	430	380
Port #9	N/A	N/A	N/A	N/A	N/A
Port #8	530	N/A	N/A	N/A	N/A
Port #7	520	510	N/A	N/A	N/A
Port #6	590	540	N/A	470	440
Port #5	600	590	390	500	440
Port #4	650	730	490	560	470
Port #3	650	820	530	620	550
Port #2	810	810	690	710	640
Port #1	720	875	910	950	970

Discussion

Flame chemistry is a complex field requiring in-depth study even when the fuel is one of known constituency. The task we have undertaken is an attempt to assess the gross factors involved in mixing and burning an extremely complex gas mixture under less than ideal conditions. This flaring study was not designed as a research project but simply a survey to determine the feasability of collecting and burning landfill gas at the Upper Ottawa Street Site.

It is apparent from the GC/MS data collected that most of the volatile organics are destroyed. A few compounds increase in concentration, however the majority of compounds are oxidized to CO_2. The chlorinated compounds are completely destroyed.

Some compounds increase in amount following combustion and a few compounds were detected in the post-flare sample that were not present in the pre-flare gas. Nitromethane is an example of the latter. It is of some concern for two reasons:

1. It is in high concentrations in comparison to the levels of other constituents.
2. The absolute identification of nitromethane could not be accomplished during the duration of these tests.

The apparently low combustion efficiencies for benzene, naphthalene and benzofuran may actually be due to formation of these compounds in the flame. Table III lists only those compounds detected in relatively high concentration in the post combustion gases. The rise in CO_2 levels after the flame, and elimination of odour by the flame, indicates oxidation of sulphur containing compounds.

Conclusions

The objectives of this study were met successfully. Firstly, the combustion efficiency of the flame is detailed in Tables II and III, and secondly, new compounds formed by the flame were detected and identified. The flame eliminated the foul odour of the gas, thereby, alleviating one of the major irritating aspects of the dump site. Dimethyl-nitrosamine was not detected in either the pre nor post combustion gases. Some compounds formed in the flame may not be detected by the methodology used in this study, however the best methodology available today was used to obtain a broad spectrum of organics.

A toxicological assessment of the combustion products is required before recommending a full scale landfill gas recovery and burning.

References

1. Edo D. Pellizzari. Measurement of Carcinogenic Vapours in Ambient Atmospheres. EPA-600/7-78-062, April 1978.

2. D.S. West, F.N. Hodgson, J.J. Brooks, D.G. DeAngelis, A.G. Desai and C.R. McMillin. Potential Atmospheric Carcinogens, Phase 2/3 Analytical Technique and Field Evaluation. Monsanto Research Corp. EPA-600/2-81-106, June 1981.

3. D.S. West F.N. Hodgson, J.J. Brooks, C.L. Heflin, T.N. Hughes and C.R. McMillin. Portable Miniature Samples For Potential Airborne Carcinogens in Micro-Environments, Phase 2 Evaluation. Monsanto Research Corporation. EPA-600/2-81-165, September 1981.

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RIC
01/04/83  5:52:00                                  DATA: 06603 #1884        SCANS    1 TO 1941
SAMPLE: TUBE#2 FIELD BLANK                         CALI: 00001 #1
RANGE: G   1,1941  LABEL: N  0, 4.0  QUAN: A  0, 1.0  BASE: U 20,  3
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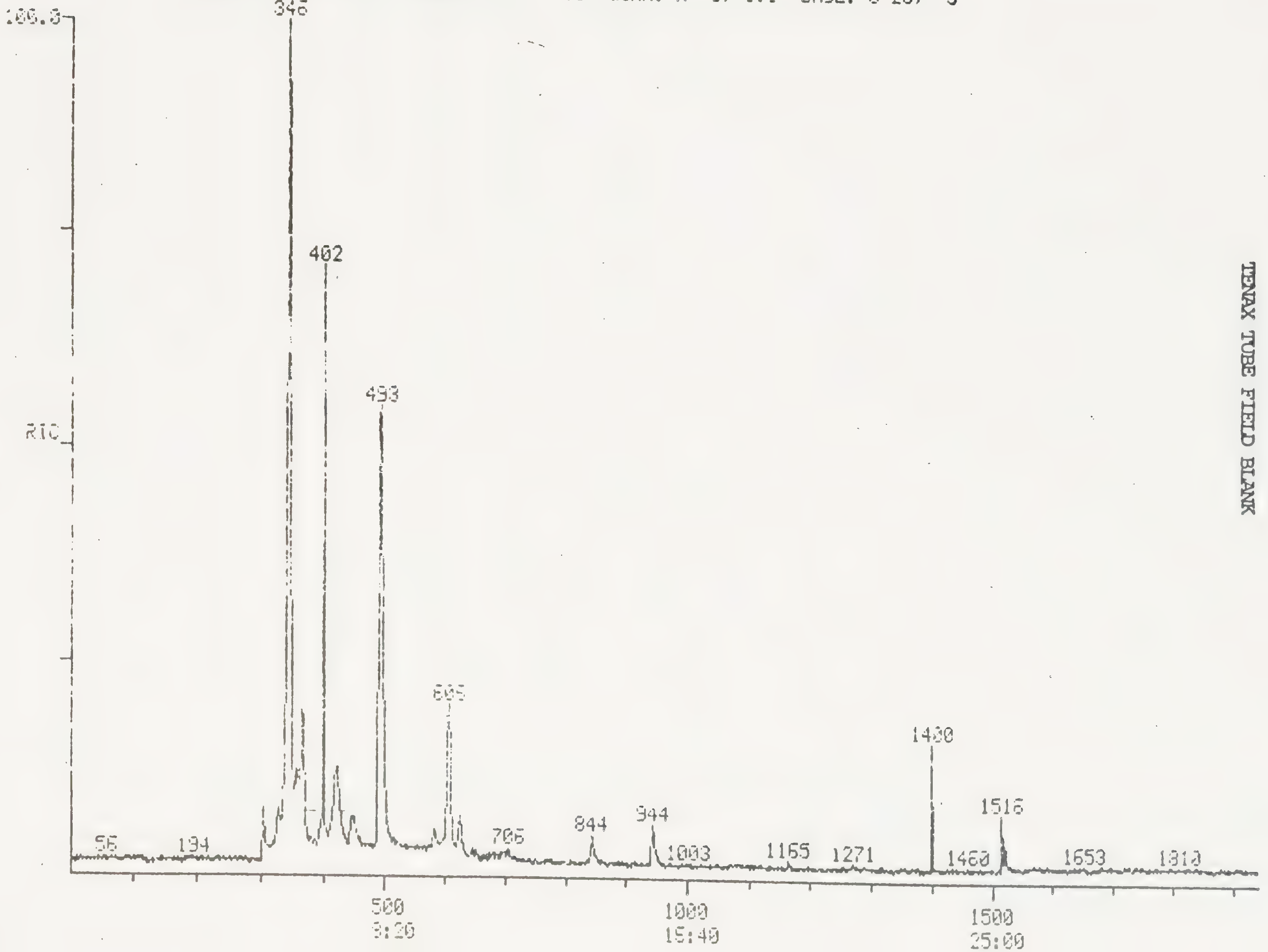


FIGURE 1

TENAX TUBE FIELD BLANK

FIGURE 2

TENAX TUBE PORT 5

FLAME ON

ONE MINUTE SAMPLE

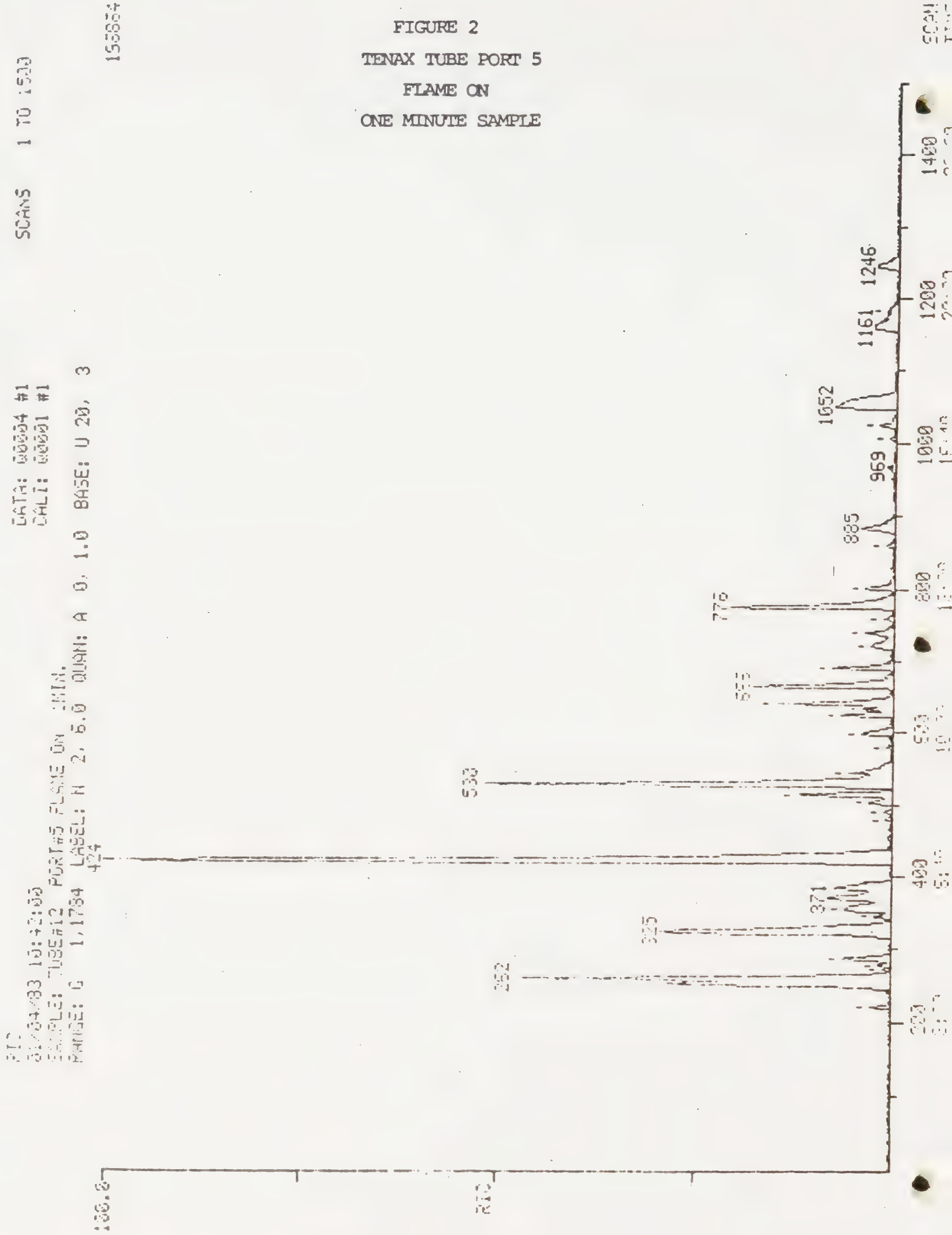


FIGURE 3

TENAX TUBE PORT 5

FLAME OFF

ONE MINUTE SAMPLE

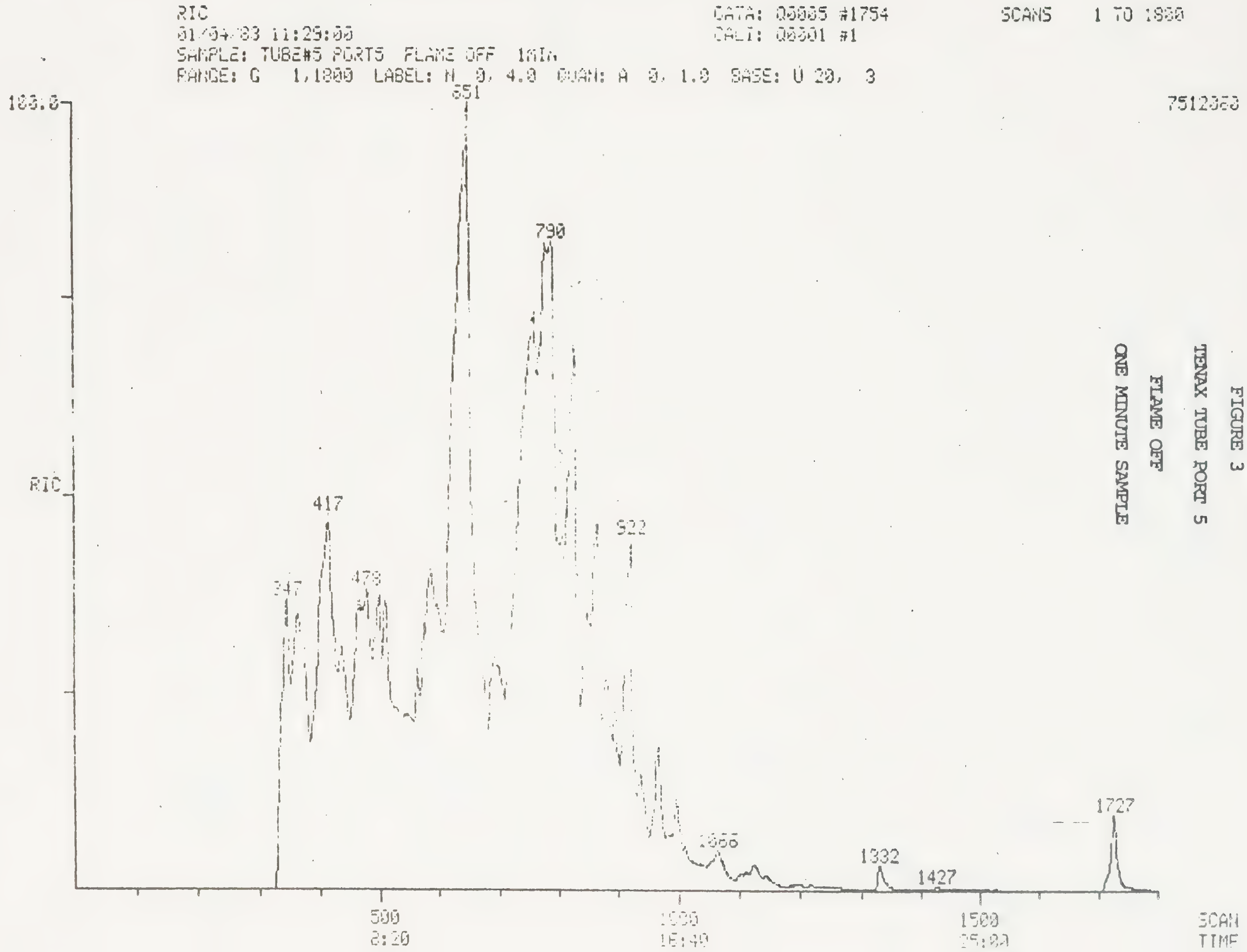


FIGURE 4

TENAX TUBE PORT 5

FLAME ON

THREE MINUTE SAMPLE

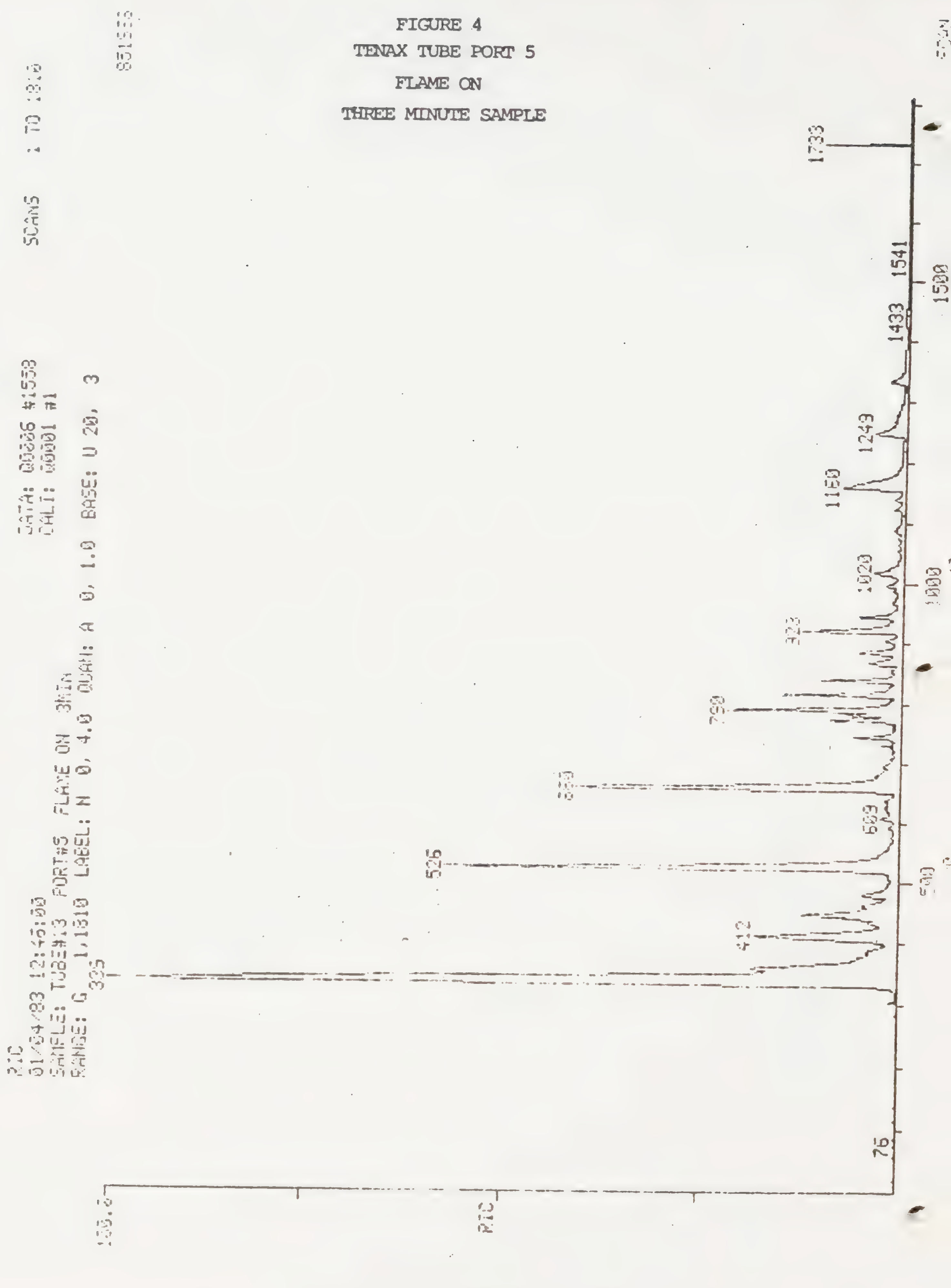
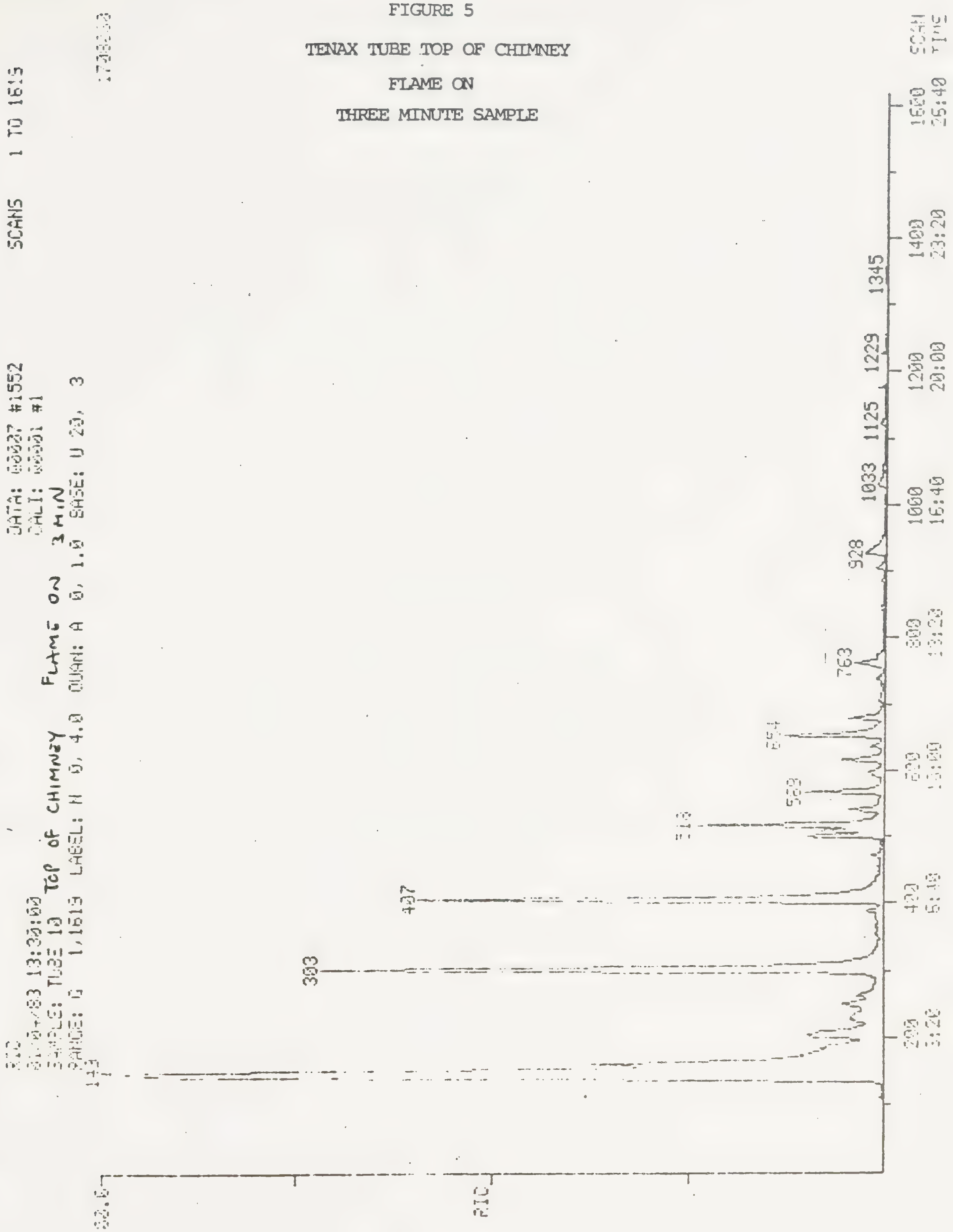


FIGURE 5

TENAX TUBE TOP OF CHIMNEY

FLAME ON

THREE MINUTE SAMPLE



APPENDIX E

MANN TESTING LABORATORIES LTD.

QUANTIFICATION OF SELECTED VOLATILE ORGANICS AT THE UPPER OTTAWA STREET LANDFILL SITE

FEBRUARY 28, 1983

QUANTIFICATION OF SELECTED VOLATILE ORGANICS AT THE UPPER OTTAWA STREET LANDFILL SITE

Submitted to

Anne Koven, Research Director
Upper Ottawa Street Landfill Study

Submitted by

Stan Hazan
Mann Testing Laboratories Ltd.
80 Galaxy Blvd., Unit 10
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M9W 4Y8

February 28, 1983

QUANTIFICATION OF SELECTED VOLATILE ORGANICS AT THE UPPER OTTAWA STREET LANDFILL SITE

A Comparison of Passive Emmission Versus Active Pumping

The successful pumping and flaring experiments conducted in December 1982 by Conestoga-Rovers & Associates and Mann Testing Laboratories concluded that collection and flaring was an acceptable method of controlling the landfill gas emmissions. The point in question was whether the gas be collected by active pumping of passive collection. Concerns were raised by the committee that although active pumping could better contain and control the landfill gas, would active pumping actually serve to increase the concentration of volatile organics in the landfill gas? With this question in mind, a pumping experiment was performed to determine the concentration of selected volatile organics with and without pumping. It was decided beforehand to quantify six key compounds known to be present in the landfill gas. These were benzene, toluene, total xylenes, naphthalene, dichlorobenzene and 1,1,1 trichloroethane. Tetrachloroethylene was added to this list during the analysis. Gas bag samples were taken from the Conestoga Well without pumping, and during various times throughout a 24 hour continuous pumping. Gas bag samples were also taken from the shallow gas probes and goose neck vents. The samples were analysed at the laboratory the same day by gas chromatography (GC/FID and GC/ECD).

The samples were screened for benzene, toluene, xylenes, naphthalene, 1,1,1 trichloroethane, dichlorobenzene and tetrachloroethylene. The naphthalene and dichlorobenzene were below the limits of detection in all samples and are not reported here. Benzene, toluene, xylenes and naphthalene were screened by GC/FID; limit of detection 3 ppm. Dichlorobenzene, 1,1,1 trichloroethane and tetrachloroethylene were screened by ECD; limit of detection 0.005 ppm. The results are listed in Table 1.

TABLE 1

CONCENTRATION OF SELECTED COMPOUNDS AT THE UPPER OTTAWA STREET LANDFILL SITE

	Concentration In PPM				
	Benzene	Toluene	Xylene	1,1,1 TCE	Tetra
Shallow Gas Probe #1	5	185	63	1.3	0.18
Shallow Gas Probe #2	4	183	56	0.3	0.17
Goose Neck Vent #1	6	126	64	0.6	0.19
Goose Neck Vent #2	5	126	80	1.7	0.21
Conn Well - No Pumping	N/A	172	45	5.2	0.32
Conn Well - No Pumping	N/A	203	63	6.9	0.35
Conn Well - Pumping 1 HR	N/A	170	61	7.1	0.16
Conn Well - Pumping 3 HR	N/A	212	75	14.6	0.55
Conn Well - Pumping 3 HR	N/A	327	150	11.8	0.58
Conn Well - Pumping 5 HR	N/A	221	91	12.4	0.53
Conn Well - Pumping 5 HR	N/A	187	75	11.5	0.40
Conn Well - Pumping 24 HR	N/A	228	73	11.5	0.39
Conn Well - Pumping 24 HR	N/A	216	68	11.7	0.35

N/A = not available due to interferences in chromatogram*
1,1,1 TCE = 1,1,1 trichloroethane (contains trace trichloroethylene)
Tetra = tetrachloroethylene
Probe #1 = gas probe nearest conn well
Probe #2 = gas probe second nearest conn well
Goose #1 = goose neck vent directly beneath conn well
Goose #2 = goose neck vent third from railway tracks
* Levels above 15 ppm would have been detected and reported

Observations

The concentration of benzene in these samples was consistently low (less than 10 ppm) and in the case of the Conestoga Well samples, the concentration could not be determined due to interferences from alkyl hydrocarbons. The concentration of toluene ranges from 126 ppm (goose neck vents) to an average of 220 ppm in the active pumping samples. Without pumping, the concentration in the Conestoga Well is similar to that in the gas probes. Continuous pumping does not appear to significantly change the concentration of toluene or xylenes. The concentration of trichloroethane appears to increase approximately two-fold when the gas is pumped (6 ppm vs 12 ppm average). The concentration of 1,1,1 trichloroethane is lower in the shallow gas probes and goose neck vents. The concentration of tetrachloroethylene increases almost two-fold when pumped (0.34 ppm vs 0.42 ppm average). This figure relates to concentrations and not total amount of contaminants. The total volume of gas removed by pumping is much higher than natural venting and would have to be considered as a separate variable.

Conclusions

The selected volatile organics appear to increase in concentration almost two-fold when pumped actively versus passisvely. This is not the case for xylenes. The concentrations are lower in the gas probes and goose neck vents than in the Conestoga Well.

CRA
Consulting Engineers

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651 Colby Drive,
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(519) 884-0510

May 5, 1983 Reference No. 906

Ms. Anne Koven
Upper Ottawa Street Landfill Study
412-20 Jackson Street West
Hamilton, Ontario
L8P 1L2

Dear Ann:

Re: Response to the Ministry of the Environment Comment on the Gas Feasibility Study - Upper Ottawa St. Landfill

The following is our response to the comments raised by the Ministry of the Environment from their review of the report entitled "Feasibility Study - Landfill Gas Control - Upper Ottawa Street Landfill" prepared by CRA in March 1983.

1. The statement "the difference in maximum temperature between a 1 to 10 ratio and a 1 to 20 ratio is only 20°C" is correct as verified by Table 5.1. In fact, on Figure 5.2, the last data point plotted at the 1 to 20 ratio is incorrect and should be plotted at 970°C rather than 992°C.

2. The samples collected during this study were all "grab samples" and no composite samples were obtained. Grab samples were obtained at the different time intervals to indicate changes in the landfill gas with time.

3. With respect to the comment on the statement "the main disadvantage of this option is that nothing would be done to reduce the emissions of 'potentially hazardous contaminants' in the gas or the odour problem at the site", this statement is made on the basis that the gas samples collected during the pumping test and from the venting at the goose neck vents indicated the presence of potentially hazardous contaminants. The gas analysis was conducted by Mann Testing Laboratories and indicated "significant amounts of alkyl hydrocarbons, chlorinated solvents, low molecular weight alcohols, THC, dioxane, ketones and C_3-C_5 benzene". A risk analysis was not undertaken to ascertain if in fact dangerous quantities of these gases could be found at the receptive points. A review of the off-site gas analysis was beyond our terms of reference, however I believe no identifiable quantities of these gases have been encountered off-site.

Continued....

4. With respect to the odour emissions from the site, there is a very distinct odour on the site and it has been indicated to us that the residents in the vicinity of the landfill have complained about these odours.

5. The landfill gas could be used to run a generator for electricity production for on-site and/or off-site usage, however, from a cursory look at this use, the option would not appear to be economically feasible. Presently, Ontario Hydro would purchase electrical power at the price of 1.5¢ to 2¢ per KWH. Studies conducted in the United States indicate that recovering landfill gas for the production of electricity requires a minimum selling price of approximately 4.5¢ per KWH. If the landfill gas system was to be installed, the selling of electricity, may help offset some of the installation costs. It should be noted that the conceptual design of the gas system was based solely on the control of landfill gas emissions. The design would have to be amended for the recovery of the gas for utilization purposes. As recommended in our report, if a gas system is to be installed at the site, the possible utilization of this energy and source should be evaluated.

6. Within the report various alternatives for the control of gas emissions have been indicated. These alternatives ranged from doing nothing, improving the landfill cover integrity and collection and flaring the landfill gas. The various options each have "short term" solutions in addition to the flaring of the gas. If the objective is to prevent gas emissions from this site, then we would recommend the active collection and flaring system.

7. The active gas collection system would most certainly include a self ignition feature for the flaring of the gas.

8. The short term gas pumping test at the Upper Ottawa Street Landfill Site indicates significant quantities of combustible gas are being generated within the landfill site. As recommended in the report, additional pumping tests should be undertaken to provide adequate design data to ensure that the system meets the objectives of controlling gas emissions and sufficient combustible gas for flaring. The additional pumping test has been recommended to be conducted on the

Continued....

long term (a minimum of one month) to ensure that the landfill gas pumping has reached a steady state. It should be recognized that after a gas system is installed the pumping rates and flow rates from each well can be controlled to ensure sufficient combustible gas for flaring.

Should you have any questions on the above, please do not hesitate to contact us.

Yours very truly,

CONESTOGA-ROVERS & ASSOCIATES LIMITED

Anthony J. Crutcher, P. Eng.

AJC/mm

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~~R. B.~~

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